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Laboratory for Isotope Geology and Geochemistry

Institute of Polar Studies
and
Department of Geology
THE OHIO STATE UNIVERSITY

GEOCHRONOLOGY OF THE TRANSANTARCTIC MOUNTAINS

Contributions by:

FACULTY: G. Faure, C.H. Shultz, and R.J. Fleck

STUDENTS: R.L. Hill, René Eastin, P.J. Barrett,
J.F. Lindsay, and R.J.E. Montigny

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First Annual Progress Report

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PREFACE

This volume contains our first report of progress in our studies of the geochronology of the Transantarctic Mountains. It was prepared for the National Science Foundation which supports this work through Grant No. GA-898X and is available for distribution free of charge to scientists engaged in research in Antarctica. Copies can be obtained by writing to G. Faure, Institute of Polar Studies, The Ohio State University, Columbus, Ohio, 43210.

The conclusions embodied in the reports are based in many instances on incomplete data and are therefore to be regarded as tentative. I request that no age determinations or other statements be quoted in papers intended for publication without my prior approval.

All age determinations were made by assuming that the half life of Rb^{97} is 1.39×10^{-11} yrs. and that the abundance of Rb^{87} is 27.85 atom per cent. Concentrations of Rb and Sr were determined by isotope dilution using calibrated spike solutions enriched in Rb^{87} and Sr^{86}, respectively. The strontium concentrations are always the total amount of Sr present and include both radiogenic and non-radiogenic components.

This report is the product of cooperation of many individuals some of whom are listed on the cover. In addition, I acknowledge the assistance of L. M. Jones in the operation of the laboratory and the help of the staff of the Institute of Polar Studies. The manuscript for this report was typed and reproduced by the Research Foundation of The Ohio State University.

G. Faure
May, 1968

ENVIRONMENT OF DEPOSITION AND PROVENANCE OF SOME BEACON ROCKS, BEARDMORE GLACIER AREA, ANTARCTICA

P. J. Barrett, G. Faure and J. F. Lindsay

Statement of the Problem

The Beacon rocks in the Beardmore Glacier area, shown in Figure 1, consist of about 2600 meters of sub-horizontal sedimentary and pyroclastic strata at least Permian and Triassic in age, although the lowest formation may be Devonian in age. The sequence has been intruded by Jurassic diabase which has formed sills as much as 300 m thick. The stratigraphy was first set up by Grindley (1963) and is now being revised (Table 1) following more detailed work in the area by Barrett (in preparation).

The environment of deposition of most of the Beacon rocks of the central Transantarctic Mountains has generally been accepted as continental (Barrett, 1965; Wade et al., 1965; Minshew, 1966); strata that include coal beds, logs, root horizons, and sandstone-carbonaceous shale cycles make up about two-thirds of the total sequence. However, Minshew (1966) believed that one unit (the equivalent to the Mackellar and Fairchild Formations of the Beardmore area) was deposited under "marine to brackish near-shore conditions."

Arguments for either marine or continental deposition of these beds have been largely intuitive; for no identifiable animal fossils have been found in these beds in the central Transantarctic Mountains. Minshew (1966) found it "difficult to visualize deposits of such wide areal extent from the Ohio Range to the Beardmore Glacier, some 800 km, having formed in a lake or in isolated lakes..." On the other hand, the Mackellar

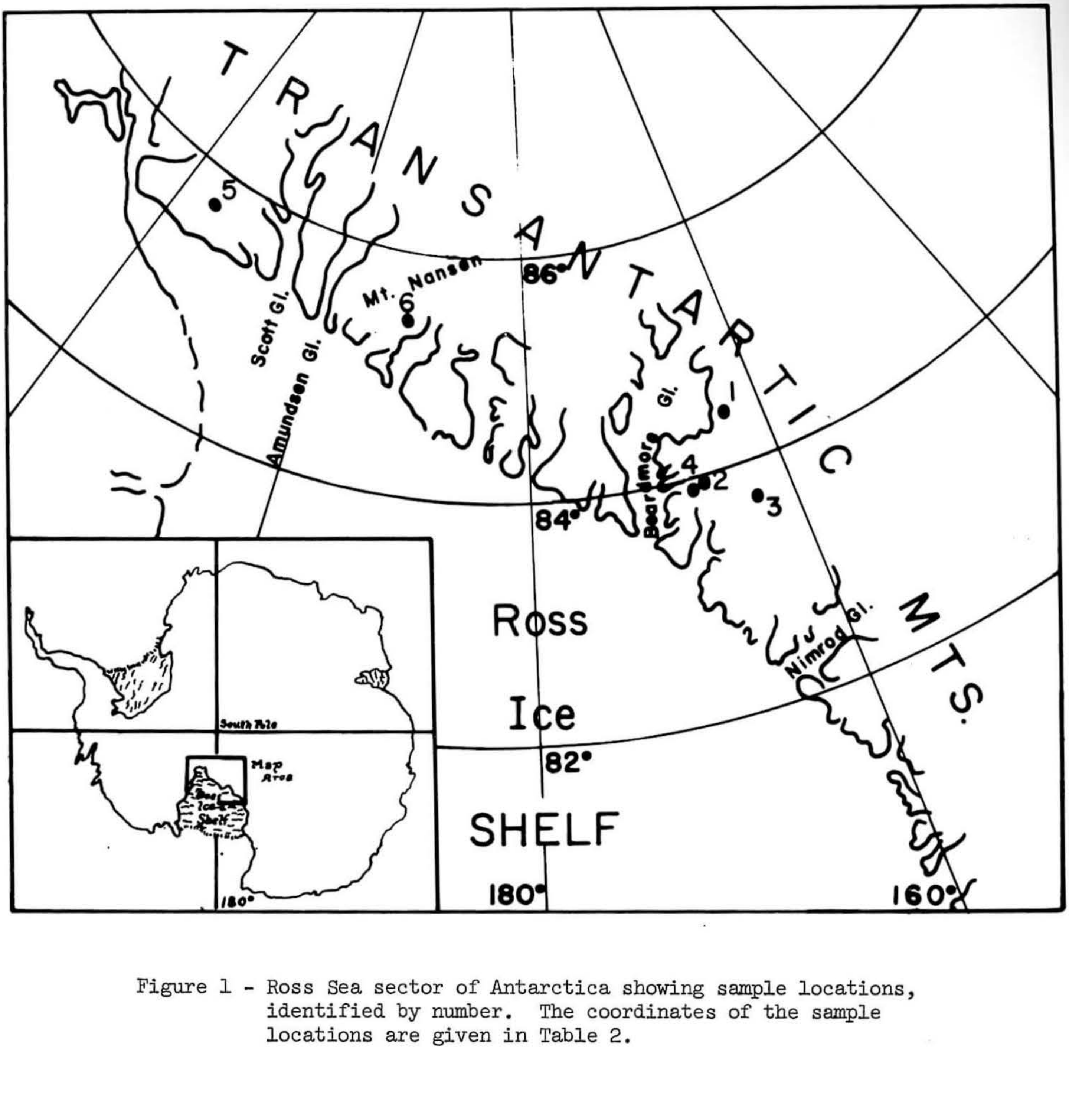

Figure 1 - Ross Sea sector of Antarctica showing sample locations, identified by number. The coordinates of the sample locations are given in Table 2.

Table 1. Stratigraphy of the Beacon Rocks of the Beardmore Glacier Area, Transantarctic Mountains

Age	Grindley (1963)	Barrett (in prep.) Lindsay (in prep.)	Thickness (meters)	Description
Jurassic	Kirkpatrick Basalts	Kirkpatrick Basalt	500+	Tholeiitic flows
	Ferrar Dolerite	Ferrar Dolerite		Numerous sills and a few dikes
	not recognized	Prebble Fm.		Volcanic mudflows, tuff, agglomerate
Triassic	Falla Fm.	Falla Fm.		Sandstone, light and dark grey shale; *Dicroidium* near base, tuff in upper part
		Fremouw Fm.	c. 650	Orthoquartzite, sandstone, green grey shale; miner coal and *Dicroidium* near top.
	not recognized			
Permian	Buckley Coal Measures	Buckley Fm.	c. 730	Sandstone, dark shale, coal, *Glossopteris*.
		Fairchild Fm.		Massive sandstone.
	Mackellar Fm.	Mackellar Fm.		Dark shale, fine sandstone.
	Pagoda Fm.	Pagoda Fm.		Tillite, sandstone, shale.
Devonian (?)	Alexandra Fm.	Alexandra Fm.	c. 400	Orthoquartzite, sandstone.
	angular unconformity			
	Lower Paleozoic - Pre-Cambrian basement.			

Formation overlies the equally extensive land-deposited debris of a wet-base glaciation (Lindsay, in preparation), and the Buckley Formation, which conformably overlies the Fairchild Formation, is a coal measures sequence of continental character that also extends at least to the Ohio Range.

In the absence of geological evidence on the marine or non-marine character of the environment of deposition of the Beacon rocks, an attempt will be made here to use the isotope composition of strontium in carbonate rocks as a possible new source of information. The basis for the use of the Sr^{87}/Sr^{86} ratio in separating marine from non-marine deposits is discussed below.

The Approach to the Problem

Under certain conditions, specified below, the Sr^{87}/Sr^{86} ratio of carbonate rocks may indicate whether they were deposited in a marine environment in contact with the open oceans or whether they were deposited in a restricted continental basin draining areas underlain by old granitic rocks.

Sr^{87} is a stable isotope of strontium and is produced by beta decay of naturally occurring Rb^{87}. The strontium existing in geologically old granitic rocks has been enriched in "radiogenic" Sr^{87} because of the decay of Rb^{87} in these rocks since their formation. Faure and Hurley (1963) estimated that the ratio Sr^{87}/Sr^{86} of granitic rocks of the continental crust is 0.725 ± 0.005, on the average. Later analyses of strontium isotope compositions in surface water samples and mollusk shells from the Canadian Precambrian Shield have generally confirmed this estimate

(Faure, Hurley and Fairbairn, 1963, and Faure, Crocket and Hurley, 1967). The isotope composition of strontium in the modern oceans is known to be constant. Faure, Hurley and Powell (1965) showed that the Sr^{87}/Sr^{86} ratio of surface water from the North Atlantic Ocean has a value of 0.7093 ± 0.0005. The same value was found by Faure et al. (1967) in water of the Hudson Bay. Additional measurements by other investigators have confirmed the value of the Sr^{87}/Sr^{86} ratio in the modern oceans and support the conclusion that the strontium in the oceans is isotopically homogeneous (Jones and Faure, 1967, and Burnett and Wasserburg, 1967). Peterman, Hedge and Tourtelot, (1967) have shown that the isotope composition of strontium in the oceans during Paleozoic, Mesozoic, and Tertiary time varied in a systematic fashion, but was constant everywhere in the world oceans at any given time.

The working hypothesis which we are using to distinguish between marine and non-marine environments of deposition can now be stated as follows:

> If the Sr^{87}/Sr^{86} ratio of a sedimentary carbonate rock of known geologic age is significantly higher (or lower) than the value of this ratio in the oceans at the time of deposition, a non-marine origin may be indicated, provided that (1) no radiogenic Sr^{87} was added to (or lost from) the rock by metamorphic processes, (2) the ratio Rb/Sr in the rock is sufficiently low so that an insignificant amount of radiogenic Sr^{87} has been formed in the rock, and (3) no radiogenic strontium is leached from the insoluble residue content of the rock during dissolution of the carbonate phase.

The excess radiogenic Sr^{87} content of carbonate rocks formed in continental basins originates as a weathering product of rocks and minerals in the drainage basin. It is conceivable that there may also be a deficiency in radiogenic Sr^{87}, relative to marine strontium, if the drainage basin is underlain by young volcanic rocks containing primary strontium derived from depth in the lower crust or upper mantle. If the Sr^{87}/Sr^{86} ratio of a carbonate rock is identical to that of marine strontium at the time of deposition, a marine origin is not necessarily indicated. Pseudo-marine isotopic composition of strontium in a continental basin may be generated coincidentally by mixing strontium from both young volcanic and old granitic sources, or by recycling of marine strontium derived by weathering of marine carbonate rocks.

With these limitations and provisions, the isotope composition of strontium in carbonate rocks may have diagnostic value and may be used to identify carbonate rocks of non-marine origin.

Experimental Methods and Results

The isotope composition of strontium has been determined for 11 carbonate rocks from the Transantarctic Mountains. Seven of these originated from the Beacon rocks of the Beardmore Glacier area while three specimens came from Mt. Fridtjof Nansen which is about 290 km south-east of the Beardmore Glacier. In addition, one specimen of trilobite-bearing limestone of middle Cambrian age from the Byrd Mountains has been analyzed. The collection sites of the specimens are identified by number in Fig. 1. The analytical results are compiled in Table 2.

The carbonate rocks were dissolved in 0.1N vycor-distilled hydrochloric acid. The insoluble residue was separated by filtration using S + S #576 filter paper. Strontium was separated from calcium and other elements by cation exchange chromatography using Dowex 50, 200-400 mesh, cation exchange resin. The isotope composition of strontium was measured on a single-filament, solid-source mass spectrometer (Nuclide Model 6-60-S).

Table 2. Analytical Data for Carbonate Rocks from the Transantarctic Mountains

Sample Number	Age	Formation	m above base	m below top	Dist. from dolerite (m)	Dolerite thickness (m)	Sr^{87}/Sr^{86}	Comments	Area	Location (see Fig. 1)
F055A	Triassic	Fremouw	545+	70	30	12	0.7116	calcite minor	Prebble Gl.	(1)
F055B	Triassic	Fremouw	545+	70	30	12	0.7084	siderite	Prebble Gl.	(1)
TMA029	Permian	Mackellar	10	80	80	200	0.7218	calcite	Tillite Gl.	(2)
L003A	Permian	Mackellar	4	71	340	c.200		calcite	Lowery Gl.	(3)
L003B	Permian	Mackellar	4	71	340	c.200	0.7182	calcite	Lowery Gl.	(3)
TPA013	Permian	Pagoda	127	47	137	200	0.7228	calcite	Tillite Gl.	(2)
TPA095	Permian	Pagoda	78	96	186	200		calcite	Tillite Gl.	(2)
TPB131	Pebble in	Pagoda Fm.	36+	102	120	200	0.7191	calcareous dolomite	Tillite Gl.	(2)
TAF146	Devon (?)	Alexandra	35+	276	540	200	0.7177	calcite	Tillite Gl.	(4)
#306	Cambrian	Leverett	-	-	-	-	0.7107	calcite	Leverett Gl.	(5)
42	Permian	Buckley	40	200+	12	150	0.7194	calcite grossularite	Mt. F. Nansen	(6)
34	Permian	Fairchild	6	146	6	120	0.7185	calcite prehnite	Mt. F. Nansen	(6)
29	Permian	Mackellar	64	52	52	120	0.7186	calcite prehnite grossularite	Mt. F. Nansen	(6)

Coordinates of Sample Locations

(1) 84°17.8'S; 164°17.0'E
(2) 83°54.3'S; 166°33.0'E
(3) 83°15.7'S; 162°52.0'E
(4) 83°51.0'S; 166°59.0'E
(5) ~85°40' S; ~146° W
(6) 85°19.0'S; 166°40.0'W

Each analysis consists of 48 or more consecutive scans. The average Sr^{87}/Sr^{86} ratio for each run was corrected for isotope fractionation by assuming a value of 0.1194 for the Sr^{86}/Sr^{88} ratio. The Eimer and Amend $SrCO_3$ Isotope Standard has been analyzed 16 times on this mass spectrometer during the last three years. The average corrected Sr^{87}/Sr^{86} ratio for this standard is 0.7083 ± 0.0004.

Discussion of the Results

The isotope composition of strontium in carbonate rocks of Permian age in the Beardmore Glacier area, as well as on Mt. Fridtjof Nansen, is remarkably constant. The Sr^{87}/Sr^{86} ratio of six specimens range from 0.7182 to 0.7228 and average 0.7199 ± 0.0008. The present Sr^{87}/Sr^{86} ratios in these carbonate rocks are clearly higher than those of the Permian oceans for which Peterman *et al.* (1967) reported a Sr^{87}/Sr^{86} ratio of 0.7072.

In order to evaluate the significance of the uniformly high Sr^{87}/Sr^{86} ratios in these carbonate rocks, we consider first the effect of the diabase sills which intrude the Beacon rocks both in the Beardmore and the Mt. Fridtjof Nansen area. It is evident from the data in Table 2 that the distance to the nearest sill varies from 6 meters (#34) to 340 meters (#L003B). It is possible that radiogenic Sr^{87} may have migrated from argillaceous Rb-rich beds into carbonate layers as a result of the increase in temperatures caused by the cooling diabase sheets. The maximum temperature in the country rock adjacent to a cooling diabase sill depends not only on the distance from the contact but also on the thickness of sill. We have therefore plotted in Fig. 2 the Sr^{87}/Sr^{86} ratios of the

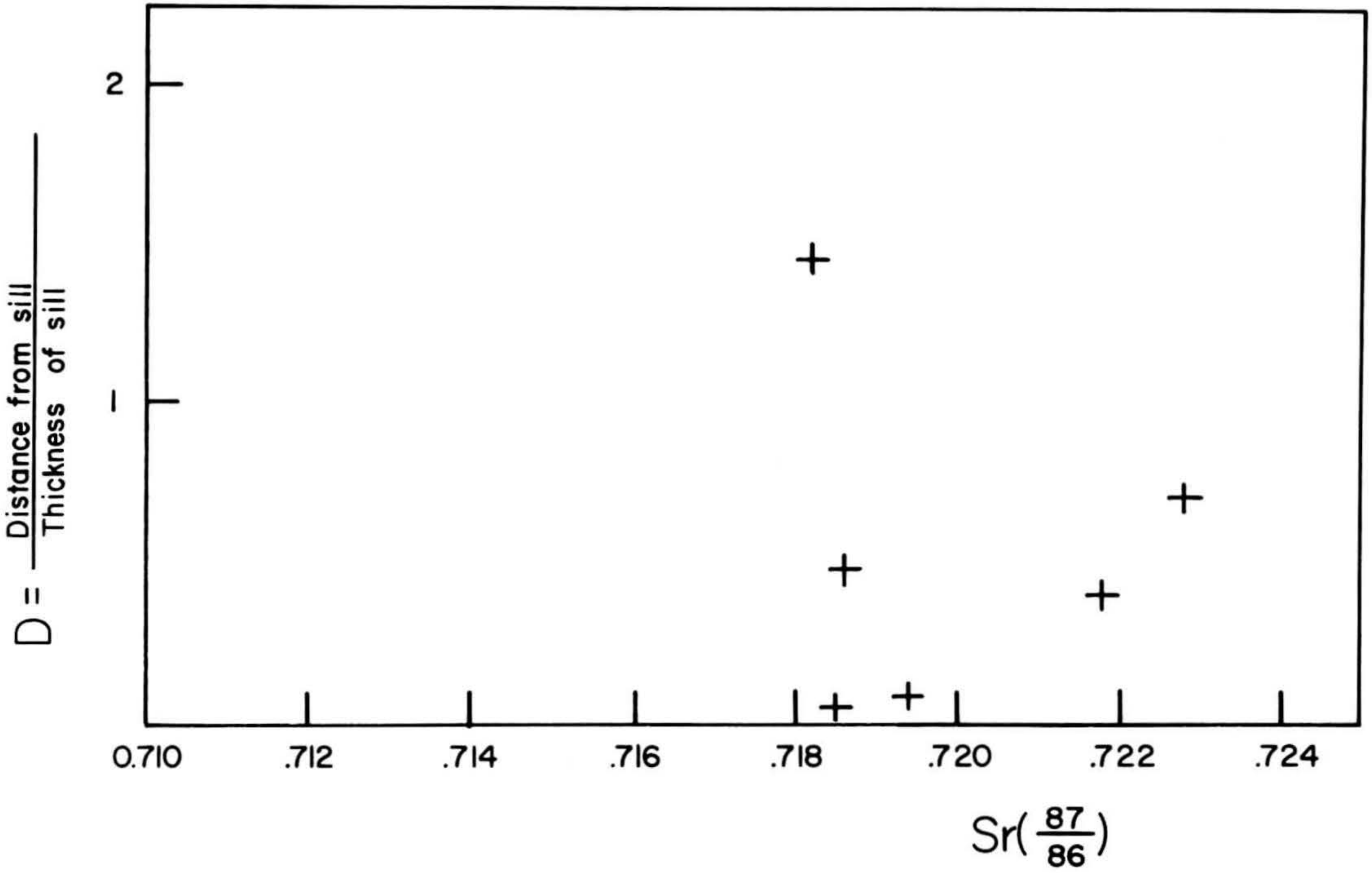

Figure 2 - Plot of the ratio $D = \frac{\text{distance from sill}}{\text{thickness of sill}}$ versus the Sr^{87}/Sr^{86} ratio of the Permian carbonate rocks. The scatter of points indicates that there is no correlation and therefore no causal relationship between the two variables.

carbonate rocks versus a function "D" which is the ratio of distance from the sill to its thickness. If a causal relationship exists between the Sr^{87}/Sr^{86} ratios and "D," then a definite correlation should be found between them. The scatter of points in Fig. 2 appears to be essentially random, not only for the carbonates of Permian age, but for the other samples as well. Thus the excess Sr^{87} of these rocks relative to Permian marine strontium is not attributable to contact metamorphism of the diabase sills. This conclusion is all the more remarkable in view of the fact that the carbonate rocks from Mt. Fridtjof Nansen have recrystallized as a result of contact metamorphism and contain prehnite and grossularite.

The rubidium and strontium concentrations of the samples have not yet been determined. Therefore, we can not exclude the possibility at this time that the excess Sr^{87} has accumulated in these rocks by decay of Rb^{87}. However, in order to increase their Sr^{87}/Sr^{86} ratios from 0.707 to 0.720 in 200-million years, these rocks must have Rb/Sr ratios of about 1.2. Values of this order of magnitude may be found in granitic rocks, but are quite unreasonable for carbonates which generally have rubidium concentrations of less than 5 ppm. We conclude, therefore, that although some Sr^{87} has undoubtedly formed by decay of Rb^{87} in the rocks, this mechanism is inadequate to explain the high Sr^{87}/Sr^{86} ratios which we have observed.

Finally, we must consider the possibility that radiogenic Sr^{87} was leached from the insoluble residue during the solution of the carbonate phase. Chauduri and Brookins (1967) have shown that acid leaching of argillaceous limestone of Permian age resulted in a slight enrichment in Sr^{87} of the acid-soluble fraction. However, the increase in the

Sr^{87}/Sr^{86} ratio of the acid-soluble fraction appeared to be less than 0.003. Since our treatment of the samples was very similar to that of Chauduri and Brookins, it seems unlikely that the high Sr^{87}/Sr^{86} ratios in the Permian carbonates of Antarctica can be explained in this way.

We conclude, therefore, that the abundance of Sr^{87} in the Permian carbonates from the Beardmore area and from Mt. Fridtjof Nansen is significant and that the observed Sr^{87}/Sr^{86} ratios reflect closely the isotope composition of strontium incorporated into the carbonates at the time of their formation. Consequently, we suggest that these carbonate rocks did not form in a marine environment.

Before we extrapolate this conclusion to all the Permian Beacon rocks of this region, a further point must be considered. The carbonate units in the sequence of sediments are generally lenticular and less than one foot in thickness. We cannot rule out the possibility at this time that they are concretionary in nature and may therefore have formed during diagenesis by precipitation from the connate pore fluid. Even if this fluid was originally trapped sea water, it is possible that the strontium in solution equilibrated isotopically with the strontium in the detrital silicate minerals. If these detrital particles originated from an old crystalline basement, they might have contributed radiogenic Sr^{87} to the pore fluid and thence to the carbonate concretions. The nature of the carbonate beds will be clarified by further work in the field which is now in progress.

If we accept a Sr^{87}/Sr^{86} ratio of about 0.720 as representative of the Permian carbonate rocks at the time of their formation, regardless of the specific mechanism, then estimates can be made of the approximate age of the source regions of the strontium. These estimates depend on the value of the initial Sr^{87}/Sr^{86} ratio for the rocks of the source region and on their assumed average Rb/Sr ratios. The lowest possible initial Sr^{87}/Sr^{86} ratio would be 0.704, which is the value commonly found in recent basalt and which would apply also to basaltic rocks even of Precambrian age. Possible values of Rb/Sr ratios range from less than 0.1 for basaltic rocks to about 1.0 for average low-calcium granites (Faure and Hurley, 1963). A more reasonable range of values is Rb/Sr = 0.15 for diorites to 0.25 for granodiorites. Figure 3 shows how the estimated present age of the source regions of the Beacon rocks depends on the Rb/Sr ratios which are assumed. It is clear that the source rocks are almost certainly Precambrian in age and most likely have ages ranging from 1.75 b.y. (Rb/Sr = 0.25) to 2.75 b.y. (Rb/Sr = 0.15). Rocks having ages of at least 1.83 b.y. have been reported from the Vestfold Hills of East Antarctica by Voronov and Krylov (1961). Slightly lower dates of up to 1.5 b.y. have been reported from the Bunger Hills by Starik et al. (1960). The inferred approximate age of the source regions which may have contributed detrital material to the Beacon rocks of the Transantarctic Mountains is therefore not unreasonable. The evidence presented here is consistent with the conclusion that the Beacon rocks may have been derived from weathering products of the Precambrian Shield of East Antarctica.

The Sr^{87}/Sr^{86} ratio of a single specimen (#TAF146) of carbonate rock from the Alexandra formation of probable Devonian age is similar to those of the Permian rocks discussed above. This specimen was collected 540 meters from the nearest diabase sill and shows no sign of contact metamorphism. Its Sr^{87}/Sr^{86} ratio is 0.7177 and is clearly higher than the value of

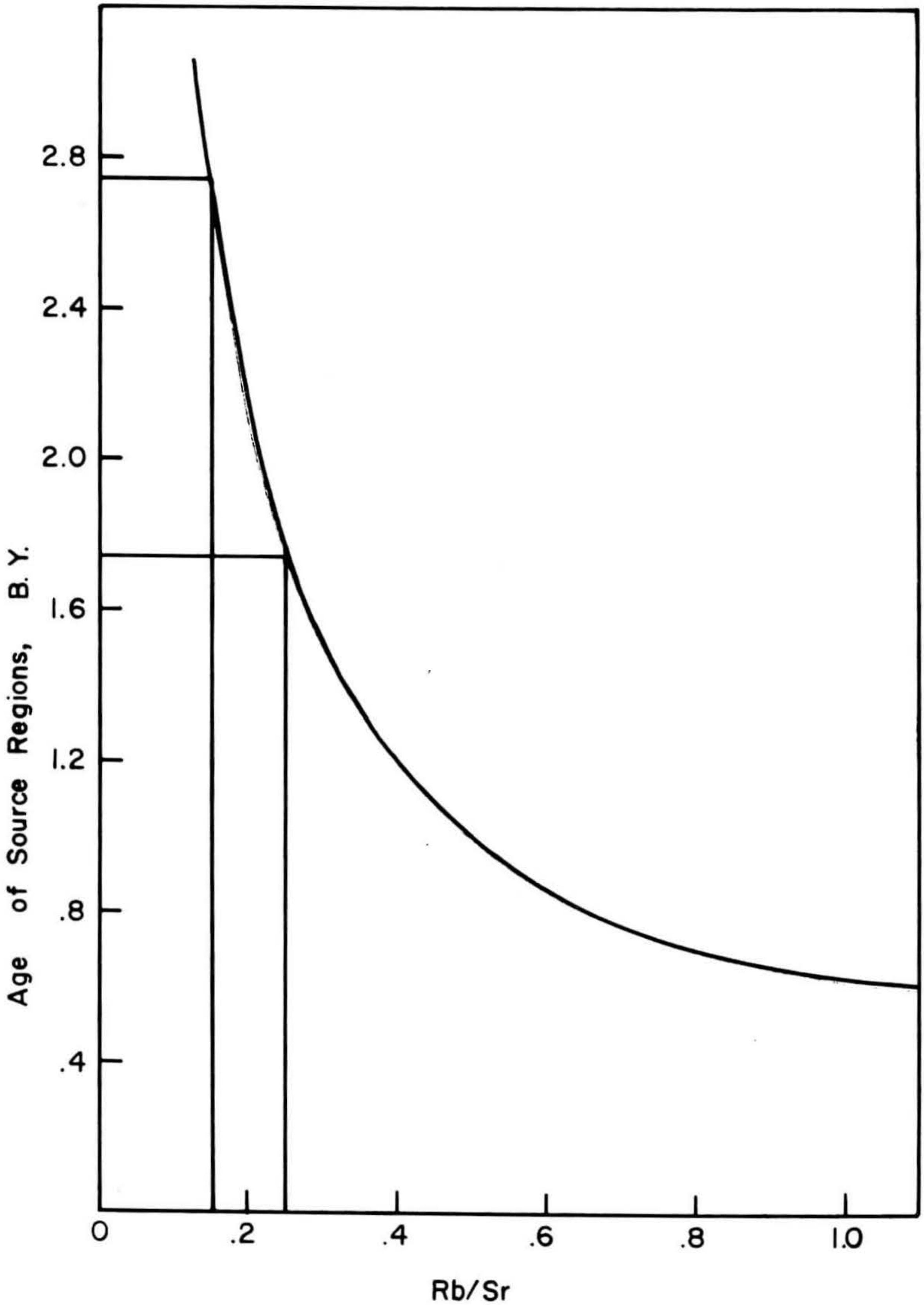

Figure 3 - Variation of the estimated present age of the source region of the Beacon rocks for different assumed Rb/Sr ratios for the source region.

this ratio in the Devonian oceans, (Sr^{87}/Sr^{86} = 0.7078), as reported by Peterman et al. (1967).

Specimen #TPB131 is a pebble of calcareous dolomite from the Pagoda formation which is thought to be a tillite of Permian age. The pebble may have been derived from the Cambrian Shackleton Limestone which was almost certainly exposed in the Permian around the head of Nimrod Glacier 200 km to the northwest in the direction of the source of the ice sheet (Lindsay, in preparation). The Sr^{87}/Sr^{86} ratio of this pebble is 0.7191.

A specimen of limestone of the Leverett formation (#306) from the Byrd Mountains has a Sr^{87}/Sr^{86} ratio of 0.7107. This rock contains fragments of trilobites of probable middle Cambrian age (Minshew, 1967) and is therefore of marine origin. The isotope composition of the strontium in this specimen is very different from those described above and is compatible with a marine origin.

Finally, two specimens (#F055A and F055B) of carbonate rock from the Triassic Fremouw formation have been analyzed. The Sr^{87}/Sr^{86} ratios of these specimens are 0.7116 and 0.7084, respectively. These values are significantly lower than those we have found in carbonate rocks of Permian age and may reflect the presence of volcanic material which is recognized in the overlying Falla formation. A marine origin of the rocks of the Fremouw formation appears to be ruled out by the presence of coal beds.

Conclusion

Although the data are incomplete and work is still in progress, certain generalizations emerge from this study. One of these is that the Sr^{87}/Sr^{86} ratios of carbonate rocks of Permian age from the Beardmore area and Mt. Fridtjof Nansen are uniformly high and average 0.7199 ± 0.0008. One possible interpretation of this information is that the environment of deposition of the Permian strata was not marine, or that the carbonate units are concretionary in nature and formed during diagenesis. In either case, the enrichment in radiogenic Sr^{87} can be used to suggest possible ages for the source regions in the range from about 1.75 to 2.75 b.y.

Another suggestion, as yet supported only by two analyses, is that the detrital material of the Triassic strata had a different provenance and includes important proportions of volcanic material.

The isotope composition of strontium of the trilobite-bearing limestone (Leverett formation) from the Byrd Mountains is consistent with a marine origin for this rock.

Acknowledgments

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REFERENCES

Barrett, P. J., 1965, Geology of the area between the Axel Heiberg and Shackleton Glaciers, Queen Maud Range, Antarctica. Part 2. Beacon Group, New Zealand J. Geol. Geophys., Vol. 8, no. 2, pp. 344-363.

Barrett, P. J., in preparation, Stratigraphy and sedimentology of the postglacial Beacon rocks in the Beardmore Glacier area, Antarctica. Ph. D. Dissentation, Dept. of Geology, The Ohio State University.

Burnett, D. S. and G. J. Wasserburg, 1967, Evidence for the formation of an iron meteorite at 3.8 × 109 years. Earth and Planetary Science Letters, Vol. 2, pp. 137-147.

Chauduri, S. and D. C. Brookins, 1967, Rb-Sr whole-rock isotopic analyses of Permian sediments. Abstract. Program G.S.A. Annual Meeting, New Orleans, p. 35.

Faure, G. and P. M. Hurley, 1963, The isotopic composition of strontium in oceanic and continental basalts. J. Petrology, Vol. 4, pp. 31-50.

Faure, G., P. M. Hurley, and H. W. Fairbairn, 1963, An estimate of the isotopic composition of strontium in rocks of the Precambrian Shield of North America. J. Geophys. Res., Vol. 68, pp. 2323-2329.

Faure, G., P. M. Hurley and J. L. Powell, 1965, The isotopic composition of strontium in surface water from the North Atlantic Ocean. Geochim. Cosmochim. Acta, Vol. 29, pp. 209-220.

Faure, G., J. H. Crocket and P. M. Hurley, 1967, Some aspects of the geochemistry of strontium and calcium in the Hudson Bay and the Great Lakes. Geochim. Cosmochim. Acta, Vol. 31, pp. 451-461.

Grindley, G. W., 1963, The geology of the Queen Alexandra Range, Beardmore Glacier, Ross Dependency, Antarctica; With notes on the correlation of Gondwana Sequences. New Zealand J. Geol. Geophys., Vol. 6, no. 3, pp. 307-347.

Jones, L. M. and G. Faure, 1967, Origin of the salts in Lake Vanda, Wright Valley, Southern Victoria Land, Antarctica. Earth and Planetary Science Letters, Vol. 3, pp. 101-106.

Lindsay, J. F., in preparation, Stratigraphy of the lower Beacon rocks in the Beardmore Glacier area, Antarctica. Ph. D. Dissertation, Dept. of Geology, The Ohio State University.

Minshew, V. H., 1966, Stratigraphy of the Wisconsin Range, Horlick Mountains, Antarctica. Science, Vol. 152, no. 3722, pp. 637-638.

Minshew, V. H., 1967, Geology of the Scott Glaciers and Wisconsin Range Areas, Central Transantarctic Mountains, Antarctica. Ph. D. dissertation, Dept. of Geology, The Ohio State University.

Peterman, Z. E., C. E. Hedge and H. S. Tourtelot, 1967, Isotopic composition of strontium in sea water throughout Phanerozoic time. Abstract. Program G.S.A. Annual Meeting, New Orleans, La., p. 176.

Starik, I. E., Ravich, M. G., Krylov, A. Ya., Silin, Yu., Atrashenok, L. Y. and Lovcjus, A. V., 1960, New data on the absolute age of rocks from East Antarctica. (In Russian). Dokl. Akad. Nauk SSSR, Vol. 134, no. 6, pp. 1421-1423.

Voronov, P. S. and Krylov, A. Ya., 1961, Age of the ancient rocks of Antarctica. (In Russian). Inform. Bull. Sov. Ant. Exp., Vol. 28, pp. 11-15.

Wade, F. A., V. L. Yeates, J. R. Everett, D. W. Greenlee, K. E. LaPrade, J. C. Shenk, 1965, The geology of the Central Queen Maud Range, Transantarctic Mountains, Antarctica. Texas Tech. College, Dept. of Geosciences, Research Report Series, Antarctic Series No. 65-1.

AGE OF THREE GRANITIC ROCKS FROM THE AXEL HEIBERG-SHACKLETON GLACIER AREA, ANTARCTICA

René Eastin

Abstract

Three granitic rocks from the Queen Maud Range were dated by the Rb-Sr whole rock method at 570 ± 350 m.y. This date is in agreement with other probable Granite Harbor Intrusives in the Transantarctic Mountains. Further work on feldspar and biotite separates is planned and should decrease the error of the age determination.

Introduction

Three granitic rocks from the Queen Maud Range in the Transantarctic Mountains were dated by the Rubidium-Strontium method. The rocks were collected by V. R. McGregor in 1963-64 while he was a member of the New Zealand Southern Field Party working in the area between the Axel Heiberg and Shackleton Glaciers. The location of this area and the sample collecting sites are shown in Figure 1.

General Geology

The geology of the area between the Axel Heiberg and Shackleton Glaciers has been described by McGregor (1965) and by Barrett (1965). The rocks in this area can be placed into two groups: (1) Precambrian to Lower Paleozoic basement which consists of strongly folded sedimentary and metamorphic rocks and is intruded by plutonic bodies and truncated by an erosion surface. McGregor (1965) places all metasedimentary rocks of the Axel Heiberg-Shackleton area into the Ross

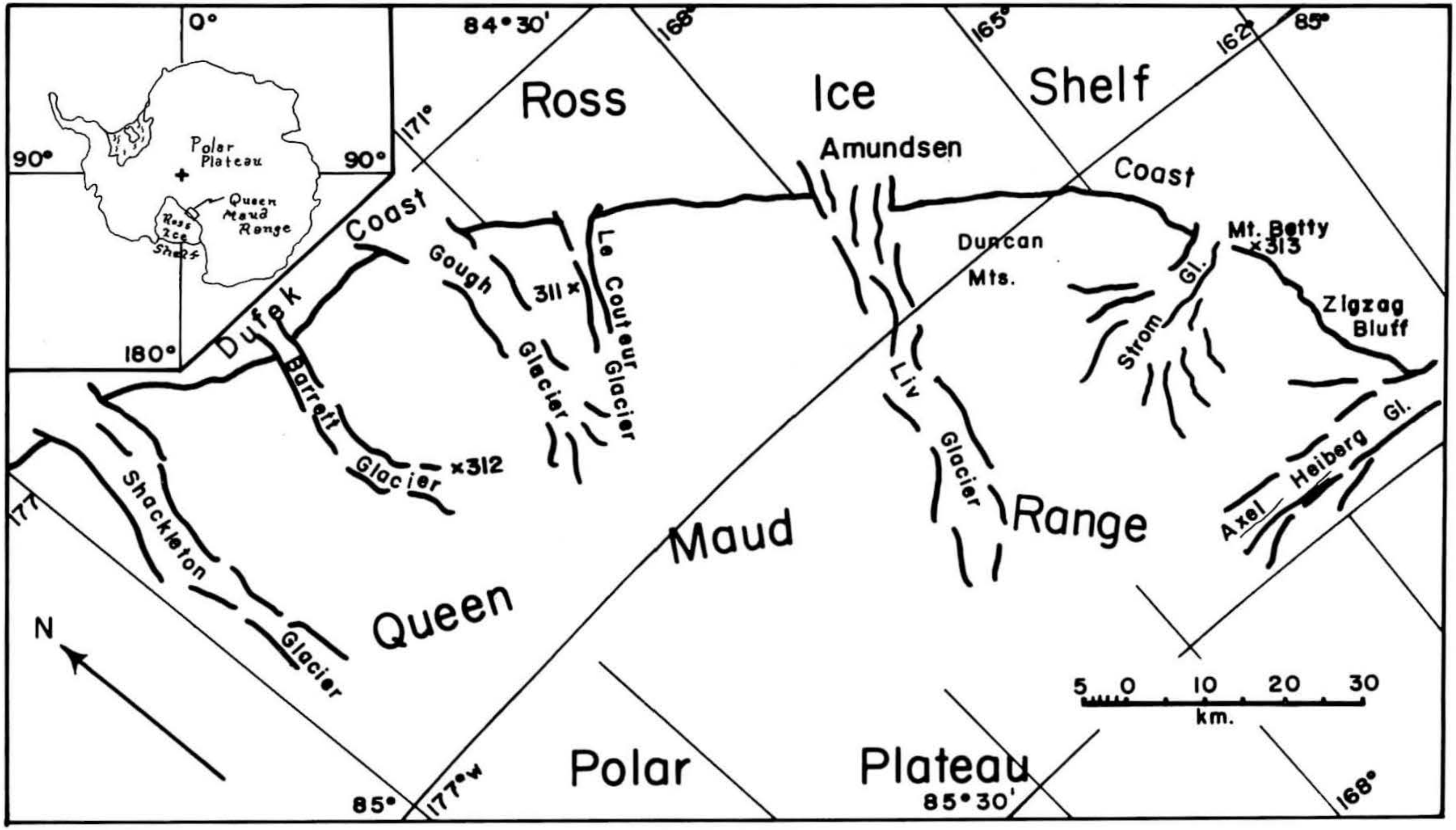

Figure 1 - Queen Maud Range and Axel Heiberg-Shackleton Glacier area of Antarctica. Sample locations are shown by "x".

Supergroup. (2) The overlying Beacon Group is a sequence of gently dipping Upper Paleozoic and Mesozoic sedimentary rocks intruded by sills of Ferrar Dolerite and overlain by comagmatic flood basalts.

Rocks intruding the Ross Supergroup which are older than the sub-Beacon peneplain were called the Granite Harbor Intrusive Complex by Gunn and Warren (1962). The name was later shortened to Granite Harbor Intrusives by Grindley and Warren (1964).

McGregor follows the practice of Gunn and Warren in dividing the Granite Harbor Intrusive rocks of the Axel Heiberg-Shackleton area into post-tectonic and pre-tectonic, depending on whether they were affected by the regional deformation occurring at the time of folding of the Ross Supergroup. McGregor found no syn-tectonic intrusives. All Granite Harbor Intrusives are believed to be genetically related to the Ross Orogeny.

Sample Description

The three rocks which have been dated by us are from the post-tectonic division of the Granite Harbor Instrusives. Unlike the pre-tectonic intrusives, they do not show secondary foliation, although some post-tectonic intrusives have a primary foliation. Most post-tectonic intrusives are adamellites and granodiorites, with some tonalites, diorites, hornblende gabbros, and some granite.

McGregor follows Johannsen's igneous rock classification (1938) and defines an adamellite as a rock in which potassium feldspar makes up 1/3 to 2/3 of the total feldspar.

Sample No. 312 (McGregor's 18.12.2) is a tonalite from the east side of Barrett Glacier, $2\frac{1}{2}$ miles SSE of Amphibole Peak, Gabbro Hills (Fig. 1). It is from a zone where a leuco-adamellite, the oldest rock in the Queen Maud Batholith, is in contact with and contaminated by a hornblende-gabbro.

Sample No. 311 (McGregor's 1/1/13) is a porphyritic adamellite from the west side of Le Couteur Glacier, $1\frac{1}{2}$ miles south of Mt. Skinner. It crops out on both sides of the Le Couteur Glacier, in the northeast part of the Gabbro Hills, and on the southwest side of Barrett Glacier. It is everywhere undeformed and is probably one of the youngest rocks in the area. McGregor describes it as coarse-grained and typically composed of biotite, smoky-grey quartz, oligoclase, and microcline. The microcline occurs as large pink phenocrysts and also in the matrix.

Sample No. 313 (McGregor's 16/11/3) is a biotite-tonalite, or trondhjemite, from Mt. Betty at the mouth of the Strom Glacier. At Mt. Betty, small irregular bodies of the biotite-tonalite have intruded and mobilized pelitic metasediments (gneiss). The contacts are diffuse. Both rocks are in turn cut by a network of dikes, including leuco-granite and pegmatite.

At the eastern corner of the Duncan Mountains a biotite-tonalite has been intruded by a stock of leuco-adamellite. The biotite-tonalite is fine-grained, unfoliated, and composed of quartz and oligoclase with 10-15% of biotite. There is negligible microcline and muscovite

Analytical Procedures and Results

An age determination was made on the three rock samples by means of the Rb-Sr whole-rock method ($\lambda Rb^{87} = 1.39 \times 10^{-11} yrs^{-1}$). Rubidium and strontium concentrations were measured by isotope dilution using spikes enriched in Rb^{87} and Sr^{86}, respectively. The strontium isotope composition was determined on unspiked samples. These data are shown in Table 1.

When the data are plotted in terms of (Rb^{87}/Sr^{86}) vs. (Sr^{87}/Sr^{86}) they form the isochron plot shown in Figure 2. On such a plot the slope of a straight line through the data points is proportional to the age of the samples. In this case, however, the data form a very poor straight line. The correlation coefficient is only 0.7724. Nevertheless, a best-fitted straight line by linear regression yields an age of 570 ± 350 million years. As expected, the error is quite large, primarily because the range of Rb^{87}/Sr^{86} ratios of the three rock samples is small (0.4655 to 1.183). Further work on mineral separates is planned and will be used to refine the present result.

Discussion

The measured age of the three granitic rocks from the Axel Heiberg-Shakleton glacier area can be compared to dates on Granite Harbor Intrusives in Victoria Land and to dates on similar rocks, such as the Hope Granite, which occurs nearer to the Axel Heiberg-Shackleton glacier area. In southern Victoria Land, Granite Harbor Intrusives have been dated as Upper Cambrian to Ordovician, 520 to 425 million years (Angino et al., 1962; Pearn et al., 1963; Deutsch and Webb, 1964).

The Hope Granite, a member of the Granite Harbor Intrusives, is one of the most common granites between the Darwin and Axel Heiberg Glaciers (Gunn and Walcott, 1962; Grindley and Warren, 1964). The

Table 1 - Rubidium and Strontium Isotope Analysis of Three Granitic Rocks from the Axel Heiberg-Shackleton Glacier Area, Antarctica

Sample	Porphyritic adamellite 311	Tonalite 312	Biotite tonalite 313
Rubidium (in ppm)	145.0	77.76	77.20
Strontium (in ppm)	354.8	245.2	479.8
(Sr^{87}/Sr^{86})*	0.7160 ±.0004	0.7111 ±.0005	0.7112 ±.0002
(Rb^{87}/Sr^{86})	1.183	0.9174	0.4655
(Sr^{86}/Sr^{88})	0.1179	0.1182	0.1185

(Sr^{87}/Sr^{86})* of Eimer and Amend
($SrCO_3$ isotope standard (15 measurements) = 0.7084 ±.0002

* = Corrected for isotope fractionation, assuming Sr^{86}/Sr^{88} = 0.1194

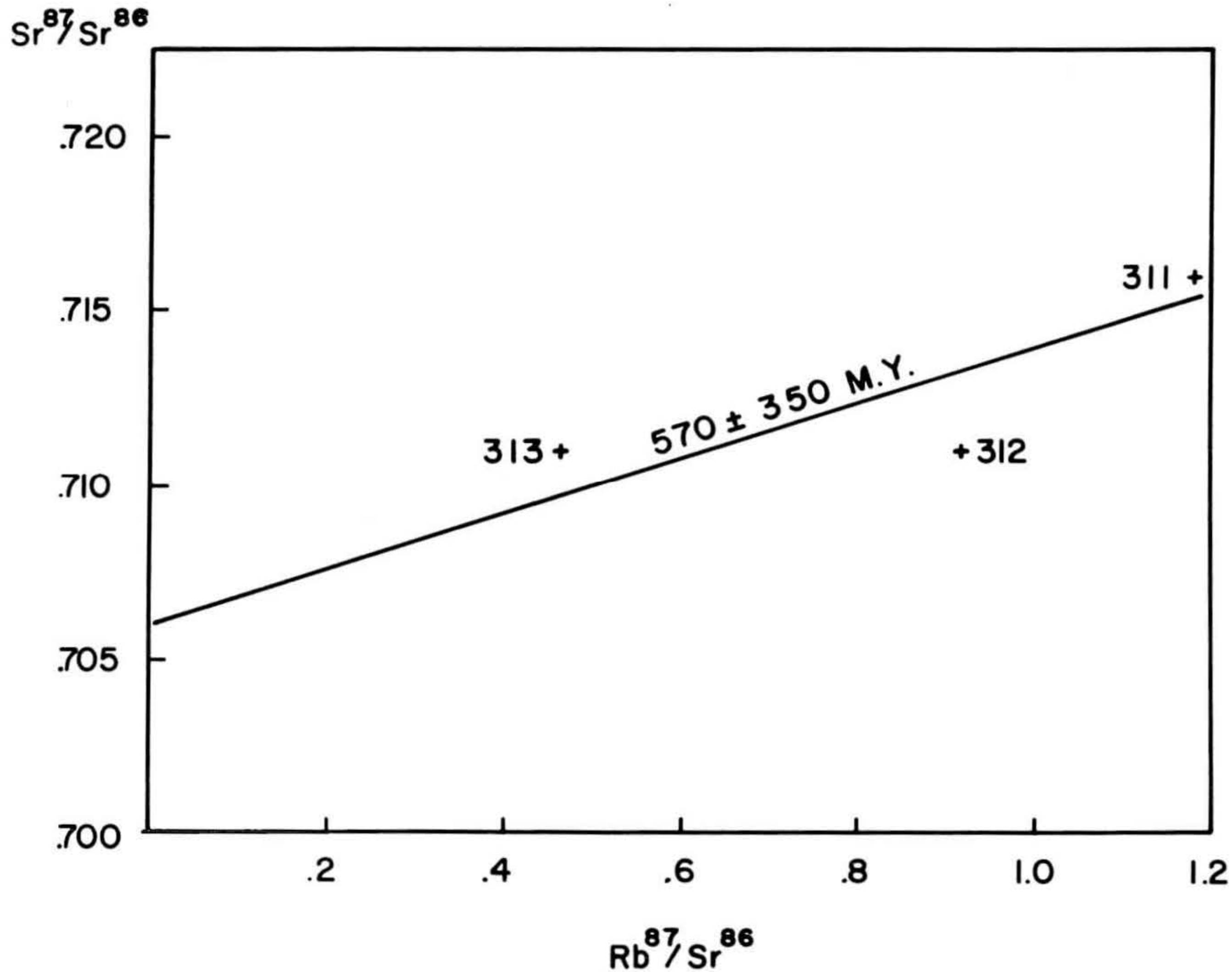

Figure 2 - Isochron diagram for the granitic rocks of the Axel Heiberg-Shackleton Glacier area.

Hope Granite also intrudes the Miller Range at the head of the Nimrod Glacier (Grindley et al., 1964). McGregor (1965) found the leuco-adamellite stocks and a muscovite-biotite granite in the Duncan Mountains to be very similar to the Hope Granite. McDougall and Grindley (1965) reported four K-Ar ages ranging from 480 to 450 m.y. on Hope Granite and associated granodiorite in the Nimrod-Beardmore Glacier area. They also obtained a 445 m.y. age on a pegmatite at Zigzag Bluff, between the Axel Heiberg and Strom Glaciers. Craddock et al., (1964) reported Rb-Sr dates on a muscovite-biotite granite at O'Brien Peak, 50 km. east of the Axel Heiberg Glacier, which may indicate that the granite was intruded at 490 m.y. and deformed at 450 m.y.

The measured age of 570 ± 350 m.y. for the three rocks collected by McGregor in the Axel Heiberg-Shackleton Glacier area is in general agreement with ages obtained on other probable Granite Harbor Intrusives in the Trans-Antarctic Mountains. Further work on feldspar and biotite separates should greatly decrease the error of this age determination.

REFERENCES

Angino, E. E.; Turner, M. D.; Zeller, E. J.; 1962: Reconnaissance Geology of Lower Taylor Valley, Victoria Land, Antarctica. Bull. Geol. Soc. Amer., 73: 1553-62.

Barrett, P. J.; 1965: Geology of the Area between the Axel Heiberg and Shackleton Glaciers, Queen Maud Range, Antarctica; Part 2 - Beacon Group. N. Z. J. Geol. Geophys., 8(2): 344-63.

Craddock, C.; Gast, P. W.; Hanson, G. N.; Linder, H; 1964: Rubidium - Strontium Ages from Antarctica. Bull. Geol, Soc. Amer., 75 (3): 237-40.

Deutsch, S.; Webb, P. N.; 1964: Sr-Rb Dating on Basement Rocks from Victoria Land - Evidence for a 1,000 million years old event. in: Antarctic Geology, North-Holland, Amsterdam.

Grindley, G. W., NcGregor, .. R., Walcott, R. I.; 1964: Outline of the Geology of the Nimrod-Beardmore - Axel Heiberg Region, Ross Dependency, Antarctica. in: Antarctic Geology, North-Holland, Amsterdam.

Grindley, G. W., Warren, G.; 1964: Stratigraphic Nomenclature and Correlation in Western Ross Sea Region, Antarctica: in: Antarctic Geology, North-Holland, Amsterdam.

Gunn, B. M., Walcott, R. I.; 1962: The Geology of the Mt. Markham Region, Ross Dependency, Antarctica. N. Z. J. Geol. Geophys. 5(3): 407-26.

Gunn, B. M., Warren, G.; 1962: Geology of Victoria Land between the Mawson and Mulock Glaciers, Antarctica. N. Z. Geol. Surv. Bull. 71, 157 pp.

Johannsen, A.; 1938: Petrography of the Igneous Rocks. 4 vols., U. of Chicago Press.

McDougall, I., Grindley, G. W.; 1965: Potassium-Argon Dates on Micas from the Nimrod Beardmore - Axel Heiberg Region, Ross Dependency, Antarctica. N. Z. J. Geol. Geophys. 8(2): 304-13.

McGregor, V. R.; 1965: Geology of the area between the Axel Heiberg and Shackleton Glaciers, Queen Maud Range, Antarctica. Part 1 - Basement Complex, Structure, and Glacial Geology. N. Z. J. Geol. Geophys. 8(2): 314-43.

Pearn, W. C., Angino, E. E., Stewart, D.; 1963: New Istopic Age Measurements from the McMurdo Sound Area, Antarctica. Nature 199 (4894): 685.

STRONTIUM ISOTOPE COMPOSITION OF THE FERRAR AND KIRKPATRICK BASALTS OF ANTARCTICA

R. L. Hill

Introduction

In a recent paper, Compston, McDougall and Heier (1968) have reported unusually high initial Sr^{87}/Sr^{86} ratios for diabase from Victoria Land in Antarctica and from Tasmania. Their data indicated that these diabases had initial Sr^{87}/Sr^{86} ratios between limits of 0.710 and 0.713. This is a very interesting discovery and has important implications with regard to the petrogenesis of these rocks and the chemical composition of their source regions at depth.

This investigation is intended to extend the work of Compston et al. (1968) to the extrusive rocks of the Ferrar Group in Northern Victoria Land and to the Kirkpatrick basalts of the Beardmore Glacier area. To date isotopic compositions of strontium have been measured for five specimens of Ferrar basalt and for three Kirkpatrick basalts. Rubidium and strontium concentrations have been determined by isotope dilution for the five Ferrar basalts.

In addition, specimens of volcanic tuff from the Falla formation from the Beardmore Glacier area are being analyzed for an age determination by the Rb-Sr method. The Falla formation underlies the Kirkpatrick volcanics and is believed to be of Triassic age. The initial Sr^{87}/Sr^{86} ratio of these tuffs will be compared to that of the overlying Kirkpatrick volcanics to obtain evidence regarding differences in the petrogenetic histories of these two rock types.

Regional Geology

The basement complex of Victoria Land, Antarctica, is composed of a series of folded Precambrian to Cambrian schists, gneisses, marbles, graywackes, and limestones called the Ross System (Gunn, 1966). This system has been intruded by the batholithic Granite Harbor Intrusives Complex, composed principally of granodiorite and granite, but with some diorite and peridotite. The granitic rocks are probably of Late Cambrian or Ordovician age. The basement complex is truncated by the Kukri peneplain on which the Beacon Sandstone rests in nonconformity.

The Beacon Sandstone is composed largely of crossbedded light colored medium - to coarse - grained sandstone and arkose, with some siltstone and coal. The formation is block-faulted, but generally flat-lying. In its type section, the Beacon Sandstone is about 3,500 feet thick, exclusive of diabase intrusions. (Hamilton, 1965). In northern Victoria Land, the Beacon Sandstone is significantly thinner. In the Rennick Glacier area, outcrops of Beacon Sandstone are only about 40 feet thick (Gair, 1967).

The Ferrar Group (Gair, 1967) comprises an extensive and complex group of intrusive rocks throughout Victoria Land and elsewhere in the Transantarctic Mountains. In the McMurdo Sound region, the Ferrar Group is represented by its intrusive phase, the Ferrar Dolerite. The dolerite has been emplaced as sills, inclined sheets and steep dikes. Concordant sills predominate, but all the intrusives contain discordant segments. Thickness of the intrusive sheets ranges from 300 to 1,500 feet, but the total thickness in a single section may be much greater. Emplacement has taken place in three general horizons. The basement sill is principally within the basement rocks, following horizontal release joints in the granites. Locally, it occupies the unconformity between the basement and the Beacon Sandstone. The peneplain sill is widely present along the Kukri peneplain. Large sills also occur entirely within the Beacon Sandstone.

Three distinct but related magma types have been recognized by Gunn (1966), on the basis of the presence of microphenocrysts of hypersthene, pigeonite, or olivine in the chilled margins of the intrusions. All of the intrusives are of tholeiitic composition, having silica values mostly within the range 52 - 56%. Significant magmatic differentiation has occurred in many of the larger sills.

In northern Victoria Land, the Ferrar Group is represented by its extrusive phase, the Ferrar Basalt. The lavas are predominantly composed of amygdaloidal and porphyritic basalt. Total thickness in a single section may exceed 4,500 feet. (Gair, 1967). Interbedded deltaic sediments occur within the Ferrar Basalt. The sediments occur as thin bodies of arkosic sandstone, siltstone, and mudstones, and commonly contain angular pebbles of Ferrar Basalt.

Potassium-argon dates for the Ferrar Dolerite pyroxene and plagioclase concentrates have been reported by McDougall (1963). The mean value of these ages is 157 m.y.. Compston et al. (1968) obtained an age of 151 m.y. by the Rb-Sr method. Two microfloras from the sediments within the Ferrar Basalt indicate an age near the Triassic-Jurassic boundary (Gair, Norris, Ricker, 1965).

The samples of this study are from Scarab Peak of northern Victoria Land, and from the Beardmore Glacier area of the Queen Alexandra Range.

The samples from Scarab Peak are Jurassic Ferrar Basalt. The samples from the Beardmore Glacier area include a series of Triassic tuffs of the Falla formation and Jurassic tuffs and basalts of the Kirkpatrick Volcanics Series. The Kirkpatrick Volcanics are thought to be correlative with the Ferrar Basalt.

Analytical Results

The analytical data available at this time are compiled in Table 1.

The isotopic analyses of strontium of the basaltic rocks from Scarab Peak have Sr^{87}/Sr^{86} ratios ranging from 0.714 to 0.717. The present Sr^{87}/Sr^{86} ratios of these rocks depend on the Rb/Sr ratios of the rocks, their initial Sr^{87}/Sr^{86} ratios, and on their age. Assuming an age of 155 m. y., their initial Sr^{87}/Sr^{86} ratios have been calculated (See Table 1) The initial Sr^{87}/Sr^{86} ratios range from 0.710 to 0.716 and **average** 0.7127. Several duplicate analyses are in progress which will refine these data. The initial Sr^{87}/Sr^{86} ratios of basaltic rocks elsewhere commonly fall inside the range 0.702 to 0.706. Evidently the basalts from Scarab Peak are anomalously enriched in radiogenic Sr^{87} compared to normal basalts. Similar high initial Sr^{87}/Sr^{86} ratios have been reported by Compston et al. (1968) for dolerite from the McMurdo Sound area of Victoria Land. The high initial Sr^{87}/Sr^{86} ratios of the Ferrar Basalt indicate either an unusually high Rb/Sr ratio of the upper mantle under Victoria Land or may be attributed to large-scale contamination of the magma with radiogenic Sr^{87} from crustal rocks. The assumption that crustal Sr^{87} is responsible for the apparent high Sr^{87}/Sr^{86} ratios would require contamination on an immense regional scale.

Table 1. Isotopic composition of strontium and concentrations of Rb and Sr in the Ferrar and Kirkpatrick basalts, and in the tuffs of the Falla formation.

Jurassic Ferrar basalt, Scarab Peak

Sample No.	$(Sr^{87}/Sr^{86})^*$	Sr, ppm	Rb, ppm	Sr^{87}/Sr^{86} initial
296	0.7158	131.6	70.4	0.7125
297	0.7141	130.4	64.7	0.7110
298	0.7139	130.0	80.8	0.7100
299	0.7171	173.6	28.0	0.7161
300	0.7155	141.2	39.5	0.7138

Triassic tuffs, Falla fm., Beardmore Glacier

Sample No.	$(Sr^{87}/Sr^{86})^*$	Sr, ppm	Rb, ppm	Sr^{87}/Sr^{86} initial
321	0.7561	-	-	-
322	0.7229	-	-	-
323	0.7394	-	-	-
324	0.7574	-	-	-
325	0.7161	-	-	-
332A	0.7100	-	-	-

Jurassic Kirkpatrick basalt, Beardmore Glacier

Sample No.	$(Sr^{87}/Sr^{86})^*$	Sr, ppm	Rb, ppm	Sr^{87}/Sr^{86} initial
332B	0.7188	-	-	-
333	0.7181	-	-	-
334	0.7163	-	-	-
335	-	-	-	-
336	-	-	-	-
337	-	-	-	-
338	-	-	-	-
339	-	-	-	-
340	-	-	-	-

* Corrected for isotope fractionation assuming $Sr^{86}/Sr^{88} = 0.1194$

Work is in progress to determine whether similar anomalous Sr^{87}/Sr^{86} ratios exist in the Kirkpatrick Volcanics of the Beardmore Glacier area. If similar high Sr^{87}/Sr^{86} ratios are found in these rocks, the area of unusual mantle geochemistry would constitute a major magmatic province.

Acknowledgements

The samples of the Ferrar basalt from Searab Peak, Northern Victoria Land, were made available to us by Dr. H. S. Gair. The Kirkpatrick basalt was collected by Dr. D. H. Elliot and the specimens of tuff of the Falla formation were obtained from Peter Barrett of the Institute of Polar Studies.

References

Compston, W., McDougall, I., and Heier, K. S., Geochemical comparison of the Mesozoic basaltic rocks of Antarctica, South Africa, South America, and Tasmania: Geochim. et Cosmochim. Acta, V. 32, No. 2, pp 129-149.

Gair, H. S., 1967, The Geology from the Upper Rennick Glacier to the Coast, Northern Victoria Land, Antarctica: N. Z. Jour. Geol. and Geophysics, V. 10, No. 2, pp. 309-344.

Gair, H. S., Norris, G., and Ricker, J., 1965, Early Mesozoic microfloras from Antarctica: N. Z. Jour. Geol. and Geophysics, V. 8, No. 2, pp. 231-236.

Gunn, B. M., 1966, Modal and element variation in Antarctic tholeiites: Geochim. et Cosmochim. Acta, V. 30, pp. 331-920.

Hamilton, W., 1965, Diabase sheets of the Taylor Glacier region, Victoria Land, Antarctica. U. S. Geol. Suvv. Prof. Paper, 456-B.

McDougall, I., 1963, Potassium-argon age measurements on dolerites from Antarctica and South Africa: J. Geophys. Res., V. 68, pp. 1535-1545.

THE AGE OF THE GALLIPOLI PORPHYRIES,
NORTHERN VICTORIA LAND, ANTARCTICA

G. Faure

Introduction

The Gallipoli porphyries occur at Gallipoli Heights in the Southern Freyberg Mountains of Northern Victoria Land. The geology of this region has been summarized recently by Gair et al. (in press). According to their description, the felsic volcanics at Gallipoli Heights overlie the Granite Harbour Intrusives of the basement complex and "consist of pink to brown porphyritic rhyolite with vague discontinuous banding in places suggestive of flow - banded lava." The age of these volcanic rocks has not yet been determined. Gair et al. (in press) reported that they appear to lie unconformably on the Granite Harbour Intrusives which are presumably Ordovician in age, on the basis of age determinations of rocks from the Wilson Hills of Northern Victoria Land. They suggested that the Gallipoli porphyries may be the extrusive equivalents of the Admiralty Intrusives which may range in age from Devonian to early Carboniferous.

Two specimens of acid volcanic rocks from the Gallipoli Heights have been analyzed for an age determination by the total-rock Rb-Sr method. The data and their interpretation are given below.

Analytical Data and Their Interpretation

The analyses were carried out by conventional methods described by Chaudhuri and Faure (1967). Concentrations of rubidium and strontium were measured by isotope dilution, while the Sr^{87}/Sr^{86} ratios were measured on separate unspiked aliquots. The analytical results are compiled in Table 1.

Table 1. Analyses for Rb and Sr and the Sr^{87}/Sr^{86} Ratio of the Gallipoli Porphyries.

Sample Number	Rb ppm	Sr ppm	$\frac{Rb^{87}}{Sr^{86}}$	$\left(\frac{Sr^{87}}{Sr^{86}}\right)^{*}_{corr}$	Remarks
315	173.3	47.8	10.5(4)	0.7606	Field No. C/76
316	100.7	46.4	6.29	0.7385	Field No. C/78

* Corrected for fractionation assuming $\frac{Sr^{86}}{Sr^{88}} = 0.1194$.

The age of these two rocks can be calculated by solving two simultaneous equations - assuming that the specimens have the same age, the same initial Sr^{87}/Sr^{86} ratio and have remained closed systems. The age which is obtained on this basis is <u>375 million years</u> and the initial Sr^{87}/Sr^{86} ratio is <u>0.7057</u>.

The Gallipoli Porphyries appear to be <u>Devonian</u> in age on the basis of a summary of the available age determinations of the Devonian period by Friend and House (1964). Thus the speculative interpretation of the stratigraphic position of these rocks by Gair et al. is confirmed. The Gallipoli Porphyries are approximately contemporaneous with the Admiralty Intrusives which occur elsewhere in Northern Victoria Land.

It is of interest to note that the initial Sr^{87}/Sr^{86} ratio of the Porphyries is essentially normal for volcanic rocks and differs significantly from the initial Sr^{87}/Sr^{86} ratios of Ferrar basalts at Scarab Peak which range from 0.710 to 0.712, according to Hill and Faure (1968). Compston, McDougall and Heier (1968) first reported similar high initial Sr^{87}/Sr^{86} for Ferrar dolerites from exposures near McMurdo Sound and elsewhere in the Transantarctic Mountains. The difference in the initial

Sr^{87}/Sr^{86} ratios indicates that the Gallipoli Porphyries are not related petrologically to the Jurassic Ferrar dolerites and basalts.

Acknowledgements

The two specimens of the Gallipoli Porphyry were collected by S. J. Carryer and were sent by Dr. H. S. Gair. René Eastin assisted with the analyses. I am grateful to all of them for their help.

References

Chaudhuri, S. and G. Faure, 1967, Geochronology of the Keweenawan Rocks, White Pine, Michigan. Econ. Geol. Vol. 62, pp, 1011-1033.

Compston, W., Ian McDougall and K. S. Heier, 1968, Geochemical comparison of the Mesozoic basaltic rocks of Antarctica, South Africa, South America and Tasmania. Geochim. Cosmochim. Acta, Vol. 32, pp. 129-149.

Friend, P. F. and M. R. House, 1964, The Devonian period. In "The Phanerozoic Time-Scale". Quart. J. Geol. Soc. Lond., Vol. 120s, pp. 233-236.

Gair, H. S., A. Sturm, S. J. Carryer, and G. W. Grindley, in press, The Geology of Northern Victoria Land. Antarctic Map Folio Series, American Geographical Society, New York, N. Y., U. S. A.

Hill, R. L. and G. Faure, 1968, Anomalous strontium isotope composition of the Ferrar Dolerite of Antarctica. Abstract. Ohio Academy of Sciences, Annual Meeting, 1968.

THE AGE OF RHYOLITE FROM THE LITTLEWOOD NUNATAKS, ANTARCTICA

G. Faure

Introduction

The Littlewood Nunataks consist of four rock outcrops between the Schweitzer and Lerchenfeld Glaciers on the eastern edge of the Filchner Ice Shelf. Their exact position is 77°53.5's and 34°10'w. The Littlewood Nunataks were first visited by helicopter from the ice breaker "U.S.S Edisto" on January 28, 1959, by J. C. Behrendt and Lt. (J. G.) Erickson, of the U. S. Navy.

The Littlewood Nunataks consist of felsic volcanic rock which has a dark brick-red appearance in outcrop. Aughenbaugh, Lounsbury and Behrendt (1965) described the petrography of this rock and reported a partial chemical analysis for it, which is reproduced here in Table 1. They concluded that "From thin-section analyses the rock is described best as a rhyolite or possibly a rhyodacite."

Table 1 - Partial chemical analysis of rhyolite from the Littlewood Nunataks*

Per cent by weight	
SiO_2	71.60
Al_2O_3	11.80
Fe_2O_3	2.04
TiO_2	0.17
CaO	0.73
MgO	0.42
Na_2O	4.15
K_2O	3.07
H_2O-	0.29
Total	94.27

* Indiana Geological Survey, Maynard Coller, analyst.

Aughenbaugh et al. (1965) reported a K-Ar age determination of 840 ± 30 million years, based on an analysis of the total rock. Therefore the volcanic rocks of the Littlewood Nunataks are Precambrian in age and may, in fact, be older than suggested by the K-Ar date. Capurro (1955) and Cordini (1959) described a total of six rock specimens from the neighboring Bertrab Nunatak. According to Aughenbaugh et al. (1965) the descriptions of these rocks suggest that they are similar in chemical and mineral composition to the volcanic rocks of the Littlewood Nunataks and they referred them collectively to the Littlewood Volcanics.

The specimen of rhyolite from the Littlewood Nunataks which was described by Aughenbaugh et al. (1965) has been analyzed for a Rb-Sr total-rock age determinations. The results are presented below.

Analytical Results

The analyses were carried out using established techniques by Chaudhuri and Faure (1967). The results are complied in Table 2.

Table 2 - Analytical results for a specimen of rhyolite from the Littlewood Nunataks

Sample Number	Rb ppm	Sr ppm	$\frac{Rb^{87}}{Sr^{86}}$	$\frac{Sr^{87}}{Sr^{86}}$
235	95.9	48.8	5.69	0.7871

From the data in Table 2 an age was calculated by assuming that the specimen has been a closed system since the time of crystallization and that it had an initial Sr^{87}/Sr^{86} ratio of 0.7040. The age of the rhyolite from the Littlewood Nunataks was found to be <u>1044 million years</u>. This age is probably an <u>upper</u> limit because the assumed value of the initial Sr^{87}/Sr^{86} ratio is close to the lowest possible value. If the actual initial ratio was greater than 0.7040, the apparent age would be lowered.

Conclusions

The age of the Littlewood Volcanics is probably greater than 840 ± 30 m.y., on the basis of the K-Ar date, and less than 1044 m.y., on the basis of the Rb-Sr date. The rhyolite from the Littlewood Nunataks appears to be the <u>oldest</u> dated rock from the Transantarctic Mountains. The Littlewood Volcanics may correlate with intrusive rhyolites which have been described by D. L. Schmidt (written communication) from the Patuxent formation of the Neptune Range in the Pensacola Mountains. Analyses of these rhyolites are in progress.

Acknowledgements

I am grateful to Dr. N. B. Aughenbaugh who sent me the specimen of rhyolite. René Eastin assisted with the analyses.

References

Aughenbaugh, N. B., R. W. Lounsbury and Y. C. Behrendt, 1965, The Littlewood Nunataks, Antarctica. Y. Geol., vol. 73, No. 6, pp. 889-894.

Capurro, L. R. A., 1955, Expedición Argentina al Mar de Wedell. Ministerio de Marina, Dirección General de Navagación e Hidrografía, p. 129-131.

Chandhuri, S. and G. Faure, 1967, Geochronology of the Keweenawan rocks, White Pine, Michigan. Econ. Geol., vol. 62, No. 8, pp. 1011-1033.

Cordini, I. R., 1959, El conocimiento geológico de la Antarctica: Instituto Antarctico Argentino, Pub. no. 6, pp. 141-145.

THE AGE OF THE WYATT FORMATION, WISCONSIN RANGE AND SCOTT GLACIER, CENTRAL TRANSANTARCTIC MOUNTAINS

G. Faure, R. J. Fleck, and R. J. E. Montigny

Introduction

The Wyatt formation was defined by Minshew (1967) on the basis of rock exposures on Mt. Wyatt which is located at 86°45'S latitude and 153°30'W longitude, just north of the junction between Poulter and Scott Glaciers in the Queen Maud Mountains. It consists of pyroclastic rocks of acidic composition and crops out extensively in the nunataks between Mts. Wyatt and Gardiner west of the Scott Glacier. The Wyatt formation makes up part of the basement complex in the Queen Maud Mountains and is believed to overlie the metasedimentary rocks of the LaGorce formation which was also defined by Minshew (1967) from the LaGorce Mountains east of Scott Glacier. (See Figure 1)

In its type locality the Wyatt formation consists of massive pyroclastic rocks composed mainly of quartz, plagioclase, rock fragments and biotite surrounded by a black, fine grained matrix. The matrix appears to be composed also of plagioclase, quartz, biotite and small lithic fragments. According to Minshew (1967) the rocks at Mt. Wyatt represent virtually unaltered pyroclastics while at Mt. Gardiner they have been metamorphosed to the quartz-albite-epidote biotite subfacies of the greenschist facies. A chemical analysis of metamorphosed rhyodacite from Mt. Gardiner is presented in Table 1.

A very similar rock formation has been found in Metavolcanic Mountain at the head of Reedy Glacier and on the Wisconsin Plateau of

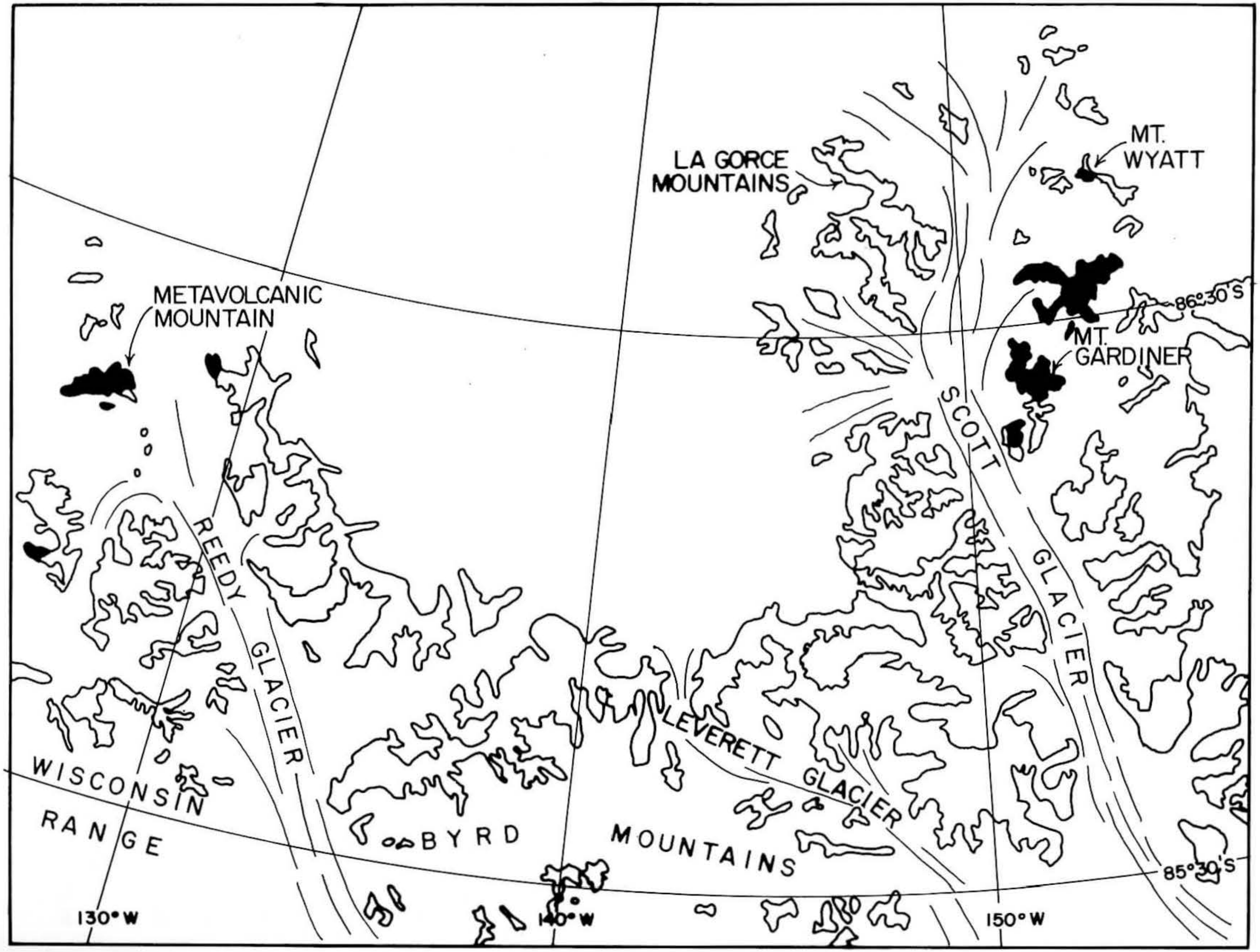

Figure 1 - Map showing the areal extent (in black) of the Wyatt formation in the Scott Glacier area and of similar metavolcanic rocks in the Wisconsin Range.

Table 1 - Chemical Composition of Pyroclastic Rock of the Wyatt Formation, Mt. Gardiner, Queen Maud Mountains, Antarctica*

	Wt%
SiO_2	67.46
Al_2O_3	15.62
Fe_2O_3	1.12
FeO	3.81
CaO	1.91
MgO	1.91
Na_2O	2.96
K_2O	3.20
MnO	0.10
TiO_2	0.68
CO_2	0.34
H_2O-	0.20
H_2O+	0.26
Total	99.89

* Taken from Minshew (1968), his number 64226

of the Wisconsin Range which is located about 175 kilometers to the east of Scott Glacier. Murtaugh (in preparation) described this rock as a "dark-grey metomorphosed igneous rock, probably of volcanic or shallow intrusive origin". According to his description, it is composed of fragments of quartz and feldspar crystals set in a matrix of aphanitic quartz and feldspar. Some of the quartz is distinctly blue. The rock appears to be massive and no primary structures were observed in the field. On the basis of lithologic similarity Murtaugh (in preparation) has suggested that the rocks of Metavolcanic Mountain in the Wisconsin Range belong to the Wyatt formation as described by Minshew.

The objective of this study is to date the metavolcanic rocks from the Wisconsin Range and to test their proposed correlation with the Wyatt formation by a comparsion of their total-rock Rb-Sr ages. To this end five specimens from Metavolcanic Mountain of the Wisconsin Range and two specimens from the Wyatt formation have been analyzed. The specimens of the Wyatt formation originated from Mt. Wyatt and from Mt. Gardiner. Three additional specimens from the Scott Glacier area are being analyzed to complete this study. The analytical data are compiled in Table 2 and will be interpreted in the following section.

Presentation and Discussion of the Data

The analytical results presented in Table 2 are plotted in coordinates of Sr^{87}/Sr^{86} and Rb^{87}/Sr^{86}, as shown in Figure 2. The data for the metavolcanic rocks from the Wisconsin Range form a straight-line isochron which indicates an age of 630 ± 14 m.y. The initial Sr^{87}/Sr^{86} ratio is 0.7034.

Table 2 - Analytical Data for Metavolcanic Rocks from Metavolcanic Mountain, Wisconsin Range and from the Wyatt Formation of the Queen Maud Range

Sample Number	Rb ppm	Sr ppm	$\frac{Rb^{87}}{Sr^{86}}$	$\left(\frac{Sr^{87}}{Sr^{86}}\right)$ *
		Metavolcanic Mountain, Wisconsin Range		
F-65-119C	164.9	128.8	3.717	0.7362
F-64-46	232.4	95.79	7.066	0.7655
F-64-45	171.5	110.4	4.514	0.7426
F-64-61	198.8	118.7	4.867	0.7465
		Wyatt Formation, Queen Maud Range		
237	150.8	172.0	2.544	0.7338
236	144.2	114.0	3.674	0.7421

* Corrected for fractionation, assuming $Sr^{86}/Sr^{88} = 0.1194$

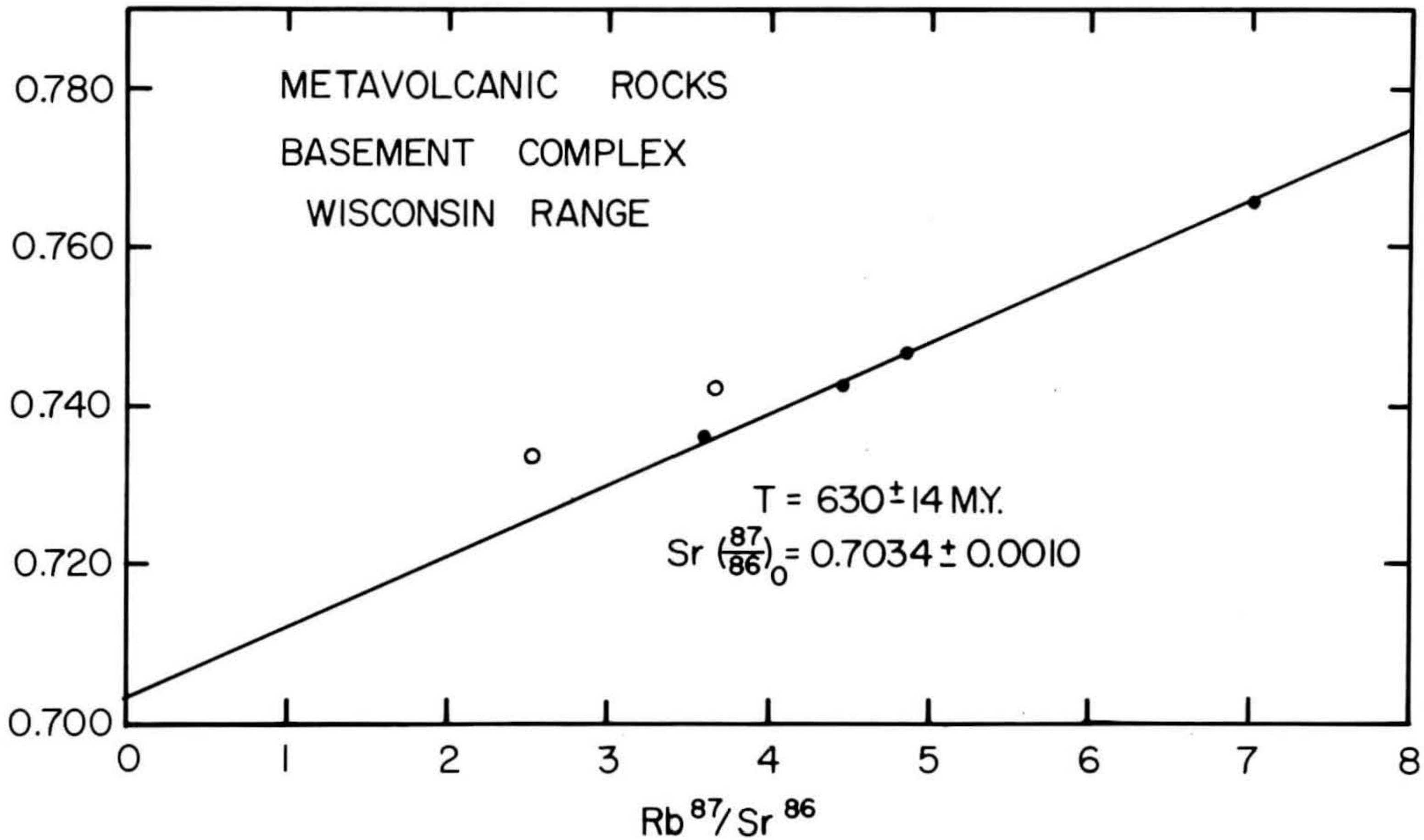

Figure 2 - Isochron diagram for the metavolcanic rocks of the Wisconsin Range. The open circles are rock specimens of the Wyatt formation from the Scott Glacier area.

The two specimens from the Wyatt formation are plotted as open circles. Inspection of Figure 2 shows that these two specimens do not plot on the isochron formed by the metavolcanic rock of the Wisconsin Range. The combined age of the two specimens is 530 m.y. with an initial Sr^{87}/Sr^{86} ratio of 0.7151.

Conclusions

The metavolcanic rocks of Metavolcanic Mountain in the Wisconsin Range have an age of 630 ± 14 m.y. Preliminary calculations of the incomplete data for the Wyatt formation of the Queen Maud Mountains suggest a somewhat lower age of 530 m.y. Further work on these rocks is in progress. The data available at this time are not sufficient to derive any firm conclusions regarding the relative ages of these rock formations.

Acknowledgements

The specimen of the Wyatt formation from Mt. Wyatt was collected by V. H. Minshew who also provided the three additional specimens of the Wyatt formation which have not yet been analyzed. R. L. Hill assisted with the analyses.

References

Minshew, V. H., 1967, Geology of the Scott Glacier and Wisconsin Range Areas, Central Transantarctic Mountains, Antarctica. Ph.D. Dissertation, Dept. of Geology, The Ohio State University.

Murtaugh, J. G., in preparation, Geology of the Wisconsin Range Batholith, Transantarctic Mountains. To be submitted for publication in the New Zealand J. of Geol. and Geophysics.

AN EVALUATION OF THE Rb-Sr AGE OF METASEDIMENTARY ROCKS, BASEMENT COMPLEX, WISCONSIN RANGE

G. Faure and R. J. E. Montigny

Introduction

The basement complex of the Wisconsin Range of the Horlick Mountains includes clastic sedimentary rocks which have been intruded by the granitic rocks of the Wisconsin Range batholith. The sedimentary rocks have also been regionally metamorphosed and folded and consist of phyllite, metagraywacke and impure quartzite. The thickness of these sedimentary rocks is not known, but may exceed several thousand meters.

These metasedimentary rocks form a series of low nunataks along the north-facing escarpment of the Wisconsin Range and can be traced westward into the Byrd Mountains. Murtaugh (in preparation) has correlated them with the LaGorce formation of the Queen Maud Mountains (Minshew, 1967) on the basis of lithologic similarity and equivalence of their stratigraphic positions. The principal areas of outcrop of the metasedimentary rocks of the Wisconsin Range and the LaGorce formation are indicated in Figure 1.

At the top of the Wisconsin Plateau metasedimentary rocks appear to be overlain by the metavolcanic rocks thought to be correlative with the Wyatt formation and described in the preceding report. The contact between the two formations is covered by scree. However, the metavolcanic rocks cap to hill while the metasedimentary rocks appear at a lower elevation along the flanks of the hill.

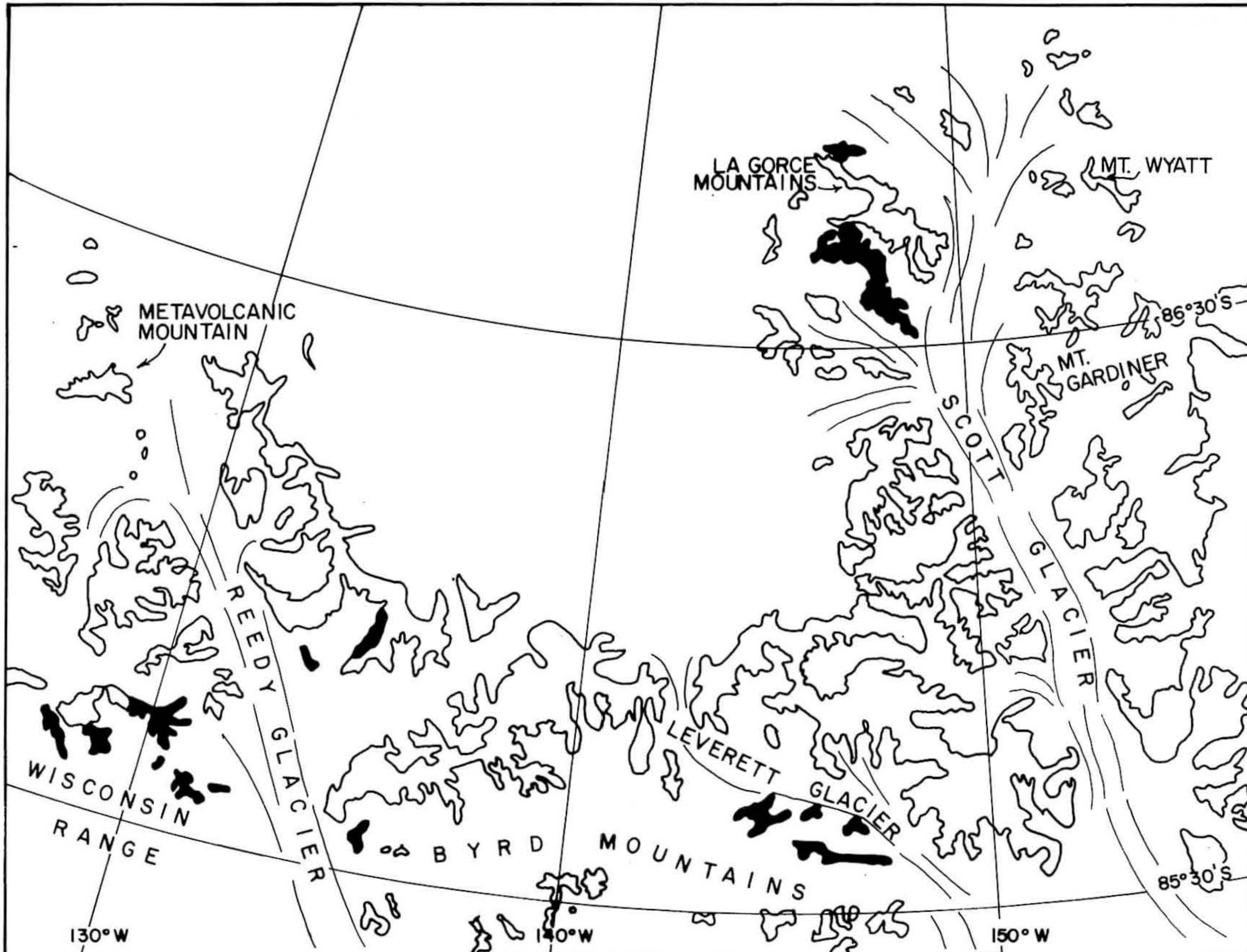

Figure 1 - Map of the central sector of the Transantarctic Mountains showing in black the outcrop pattern of the LaGorce formation.

A suite of specimens of metasedimentary rock were collected from one of the numerous low nunataks along the northern edge of the Wisconsin Range. At the collecting site the metasediment was intruded by several small masses of granitic rock composed of feldspar phenocrysts in a matrix of feldspar, muscovite, biotite, quartz and garnet. Eight specimens of metasedimentary rock within a few hundred feet of the contact were selected for an age determination by the Rb-Sr method. In addition, seven specimens of granitic rock and aplite from the Wisconsin Range batholith were analyzed, including one sample (# F-64-102B) from the stock which intrudes the metasedimentary rocks at the site where samples were collected for dating.

Analytical Results

The analytical results are compiled in Table 1 and are plotted on strontium evolution diagrams in Figures 2 and 3. The metasedimentary rocks plotted in Figure 2 form a linear array whose slope indicates an apparent age of 462 ± 17 m.y. This represents the time elapsed since the strontium in these rocks was most nearly isotopically homogeneous. It is almost certainly not representative of the time elapsed since deposition of these metasedimentary rocks.

A possible interpretation of the meaning of this data can be derived from the fact that the sedimentary rocks which we have analyzed originate from the contact zone of a granitic intrusive. A suite of specimens of these granitic rocks has been analyzed and the data are plotted in Figure 3. The slope of the resulting isochron can be used to calculate an age of 490 ± 12 m.y. for these rocks. This date

Table 1 - Analytical Data for Metasedimentary Rocks and Intrusive Quartz Monzonites and Aplites, Wisconsin Range, Horlick Mountains

Sample Number	Rb ppm	Sr ppm	$\frac{Rb^{87}}{Sr^{86}}$	$\left(\frac{Sr^{87}}{Sr^{86}}\right)_{corr}$
		Metasedimentary Rocks		
F-64-103A	131.6	173.9	2.195	0.7315
F-64-103B	78.6	199.1	1.144	0.7237
F-64-103C	225.9	48.79	13.53	0.8023 0.8024
F-64-103D	114.9	158.2	2.109	0.7357
F-64-103E	222.0	125.8	5.128	0.7445
F-64-103F	114.3	199.5	1.662	0.7253
F-64-103G	253.7	48.88	15.20	0.8166
F-64-103H	91.8	91.58	2.911	0.7375
		Quartz Monzonite and Aplite		
F-64-19B	158.2	156.9	2.922	0.7266
F-64-27B	219.3	25.27	25.57	0.8886
F-64-69B	108.4	278.0	1.878	0.7174
F-64-70B	183.7	273.8	1.942	0.7184
F-64-76B	625.1	59.67 57.86	30.89	0.9094 0.9110
F-64-84B	201.6	195.8	2.984	0.7272
F-64-102B	234.9	41.05	17.38	0.8263

* Corrected for isotopic fractionation by assuming $Sr^{86}/Sr^{88} = 0.1194$

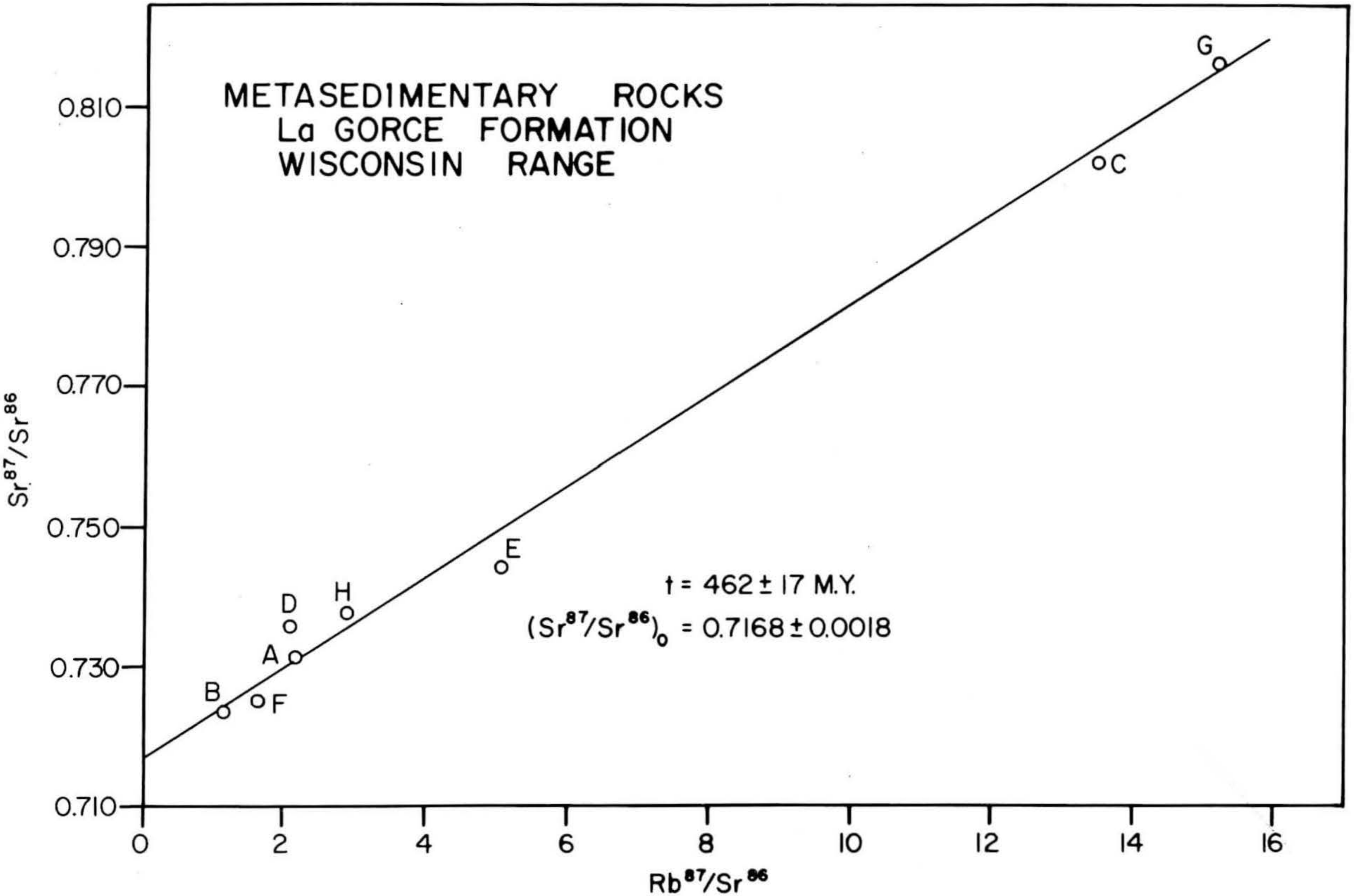

Figure 2 - Apparent isochron for the metasedimentary rocks of the LaGorce formation from the Wisconsin Range.

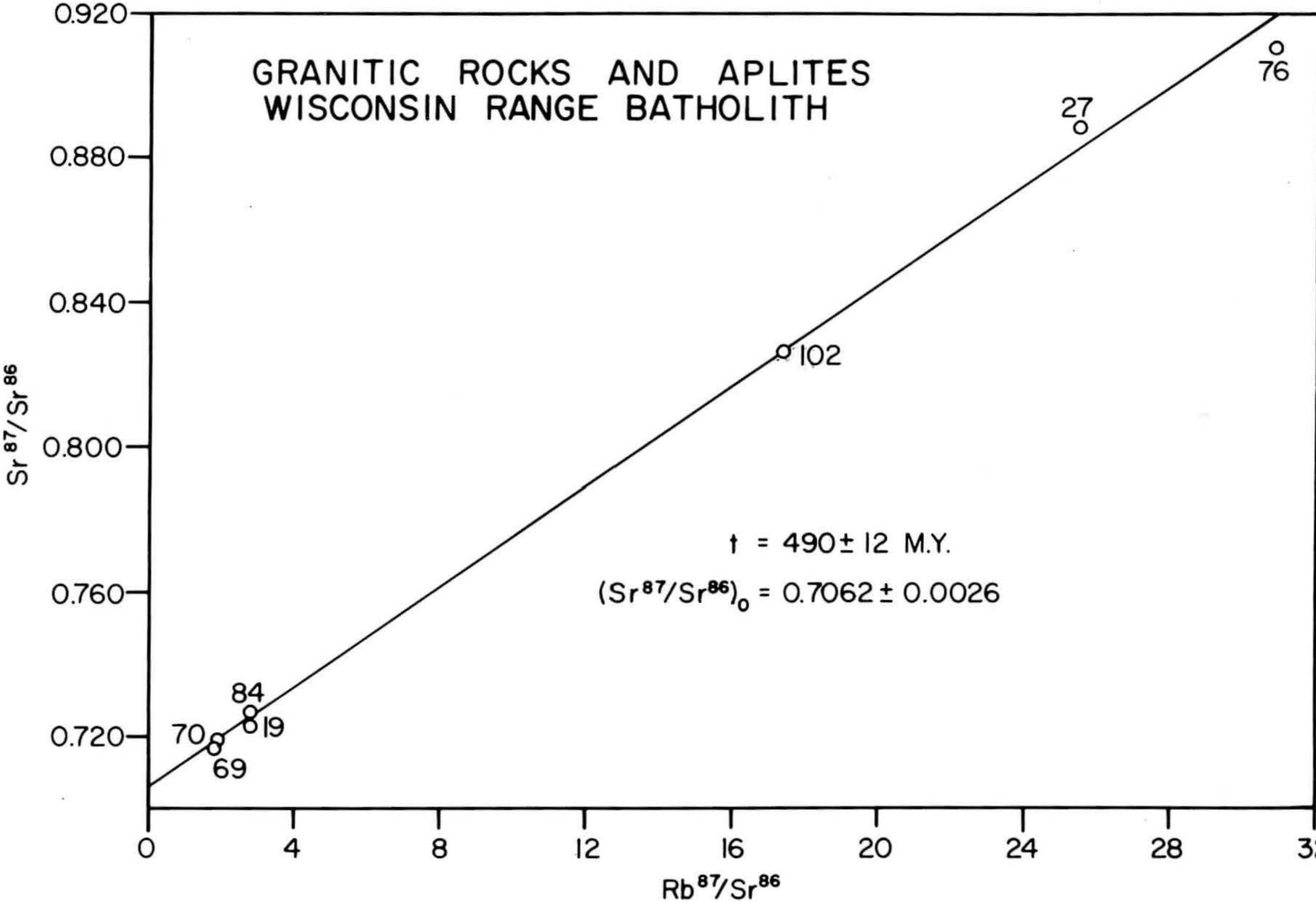

Figure 3 - Isochron diagram for granitic rocks and aplites of the Wisconsin Range batholith.

is interpreted as the time of crystallization of these rocks which occurred during the Lower Ordovician period.

The apparent age of the metasedimentary rocks (462 ± 17 m.y.) and the age of the granitic rocks (490 ± 12 m.y.) are very similar and may well be identical. We suggest, therefore, that the metasedimentary rocks included in our study were isotopically homogenized by the intrusion of granitic rocks during the Lower Ordovician period. The true age of the metasedimentary rocks must be greater than the age of the intrusives. Field evidence suggests that the metasedimentary rocks are overlain by the metavolcanic rocks of the Wyatt formation (see elsewhere in this report) for which we have obtained an age of 630 ± 14 m.y.. It is therefore possible that the metasedimentary rocks are older than 630 m.y., or were deposited in late Precambrian time.

Acknowledgements

The specimens for this study were collected by G. Faure with support from NSF Grant No. GA-136. René Eastin and R. L. Hill assisted with the analyses.

References

Minshew, V. H., 1967, Geology of the Scott Glacier and Wisconsin Range Areas, Central Transantarctic Mountains, Antarctica. Ph.D. Dissertation, Dept. of Geology, The Ohio State University.

Murtaugh, J. G., in preparation, Geology of the Wisconsin Range batholith, Transantarctic Mountains. Submitted for publication to the New Zealand J. of Geol. and Geophysics.

AGE AND PETROGRAPHY OF ACID VOLCANIC ROCKS FROM THE CENTRAL TRANSANTARCTIC MOUNTAINS

G. Faure, C. H. Shultz and D. L. Schmidt

Abstract

Suites of acid volcanic rocks from the Byrd Mountains, the Long Hills and the Neptune Range of the Pensacola Mountains have been studied to attempt regional correlations by means of Rb-Sr age determinations, petrographic descriptions and bulk chemical analyses.

Introduction

Volcanic rocks of acid to intermediate chemical composition have been observed in several ranges of the Transantarctic Mountains. This report will focus attention on the volcanic rocks in the Byrd Mountains, the Long Hills and the Pensacola Mountains of the central sector of the Transantarctic Mountains. Our objective is to determine to what extent these volcanic rocks can be correlated on the basis of Rb-Sr age determinations, detailed petrographic descriptions and comparisons of their bulk chemical compositions. The three mountain ranges in which these volcanic rocks occur encompass a distance of about 1000 km along the strike of the Transantarctic Mountains and are separated by large areas of ice. Direct correlation by tracing these rocks in outcrop is therefore impossible. (See Figure 1)

Regional Geology

The volcanic rocks in each of the three mountain ranges form part of the basement complex which is overlain nonconformably by the late

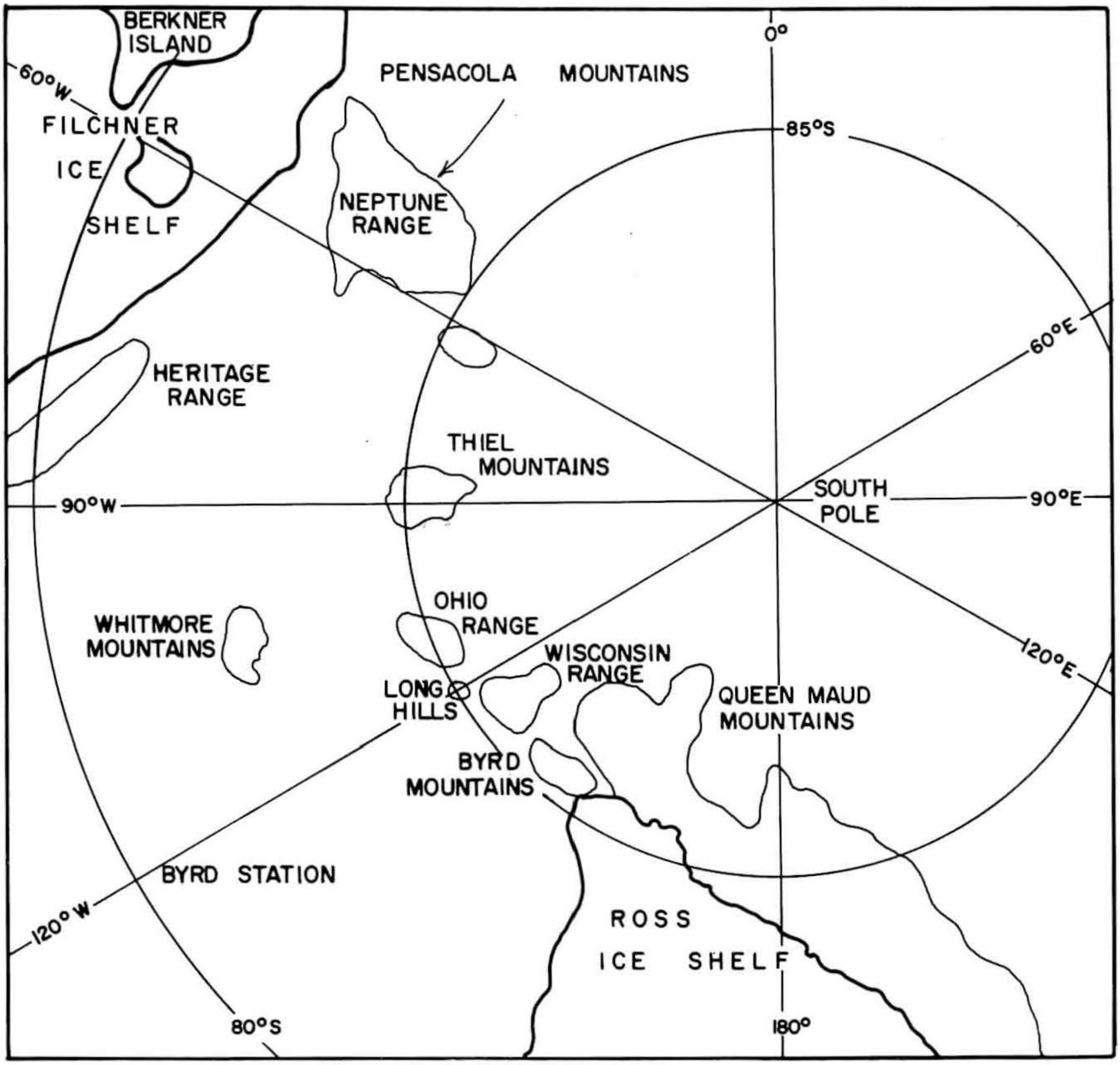

Figure 1 - Index map of the mountain ranges of the Central Transantarctic Mountains.

Paleozoic and Mesozoic rocks of the so-called Beacon Group. In the Byrd Mountains and in the Neptune Range of the Pensacola Mountains the felsic volcanic rocks overlie fossiliferous marine carbonate rocks of Middle Cambrian age. The stratigraphic age of the volcanic rocks in the Long Hills is unknown since they are not associated in the outcrop with any sedimentary rocks.

In the following sections of this report we present summaries of the regional geology for each of the three mountain ranges together with petrographic descriptions and chemical compositions of the felsic volcanic rocks.

1. The Leverett Formation of the Byrd Mountains

The Leverett formation was defined by Minshew (1967) for exposures of rocks at Mt. Webster in the western part of the Byrd Mountains north of the Leverett Glacier. It includes more than 1000 meters of strata consisting of coarse-grained arkosic sandstone at the bottom overlain by pebbly mudstone, silty shale, and a succession of shale and carbonate beds. The uppermost limestone unit is overlain in turn by pyroclastic rocks of rhyolitic composition interbedded with coarse-grained conglomeratic sandstone. Four specimens of felsic volcanic rock were analyzed for an age determination by the Rb-Sr method. In addition, a bulk chemical analysis was obtained for one of the specimens (#228) as shown in Table 1.

Rocks from the Leverett formation in the Byrd Mountains differ markedly from the acid volcanics of the Long Hills and the Neptune Range which are described later. The most notable feature is that the

Table 1 - Chemical Analyses of the Acid Volcanic Rocks from the Basement Complex of the Central Transantarctic Mountains

Lab. No. Constituent	228 1	128-2 2	128-4 3	128-10 4	292 5	293 6	294 7
SiO_2	66.48	65.93	66.72	63.05	76.98	76.88	73.71
TiO_2	0.80	0.87	0.83	0.82	0.11	0.28	0.11
Al_2O_3	13.52	14.33	13.55	13.70	12.06	11.95	14.12
Fe_2O_3	0.54	0.01	0.69	0.54	1.22	1.08	1.52
FeO	4.34	5.43	5.81	4.13	0.27	0.38	1.40
MnO	n.d.	n.d.	n.d.	n.d.	0.01	0.02	0.05
MgO	1.57	1.32	1.77	1.24	0.17	0.08	0.38
CaO	1.90	1.62	1.03	4.00	0.19	0.55	1.79
Na_2O	2.76	0.25	2.02	3.26	2.21	3.31	0.91
K_2O	4.10	5.33	5.31	5.32	5.88	4.73	3.64
H_2O +	2.28	2.82	1.66	1.65	0.52	0.32	1.67
H_2O -	n.d.	n.d.	n.d.	n.d	0.08	0.05	0.27
P_2O_5	0.124	0.176	0.170	0.199	0.02	0.07	0.02
CO_2	1.44	1.37	0.40	1.55	0.01	0.01	0.15
Totals	99.85	99.46	99.96	99.46	99.73	99.71	99.74

1. Specimen # 228, acid volcanic rock, Leverett formation, Byrd Mountains. A.S. McCreath and Son, analyst.

2. Specimen # 128-2, acid volcanic rock, Todd Ridge, Long Hills, A. S. McCreath and Son, analyst.

3. Specimen # 128-4, acid volcanic rock, Todd Ridge, Long Hills. A. S. McCreath and Son, analyst.

4. Specimen # 128-10, acid volcanic rock, Todd Ridge, Long Hills. A. S. McCreath and Son, analyst.

5. Specimen # 292 (Field No. N2.1.12.64A by D. L. Schmidt, U.S.G.S.) Hawkes hypabyssal rhyotic intrusive from the west side of "Hawkes camp" valley, southern Neptune Range. Analyzed by U.S. Geol. Survey, Rept. No. 65DC-55.

6. Specimen # 293 (Field No. 5.25.12.29.63 by D. L. Schmidt, U.S.G.S.) Hawkes hypabyssal rhyolitic intrusion, from the middle "Bragg" valley, southern Neptune Range. Analyzed by U.S. Geol. Survey, Rept. No. 65DC-55.

7. Specimen # 294 (Field No 5.2.12.9.63 or 5 2-11.12.9.63 by D. L. Schmidt, U.S.G.S.) Pyroclastic rhyolite, an autolithic breccia occurring in the basal part of the Elliot sandstone. Specimen is from the Pemberton section about 1 mile west of Wiens Peak, southern Neptune Range. Analyzed by U.S. Geol. Survery, Rept. No 65DC-55.

Leverett formation has apparently gone through a low-grade metamorphic event under severe shear stress. The rocks are best described as grayish-black, blastopsammitic to blastoporphyritic, chlorite-muscovite phyllites showing fair to strong lineation. Primary or original minerals include oligoclase (An27) showing remarkable mechanical deformation features, orthoclase, quartz, muscovite, apatite, magnetite, and leucoxene. The feldspars are typically somewhat altered to sericite, chlorite, and epidote, and potash feldspar is selectively replaced by carbonate in some sections. Minerals that are believed to have develop developed under metamorphic conditions include biotite, epidote, chlorite, muscovite, quartz, and zeolites. This disequilibrium assemblage may represent partial retrograde metamorphism, or more likely, failure to attain equilibrium during prograde metamorphism because the time period during which metamorphic conditions prevailed was too brief. Complicating the mineral assemblage, is unequivical evidence for a hydrothermal event or events, which was in part penecontemporaneous with shearing and in part post deformation. Material introduced largely as veins by this mechanism includes quartz, chabazite and other zeolites (probably laumontite or thompsonite), and some carbonate and epidote. Since calcite is underformed, it presumably was introduced during a late stage of hydrothermal activity after deformation had effectively ceased, or it was introduced by a second, post-deformational hydrothermal event.

Texturally, the rock is dominated by well-developed foliation that pinches and swells around blastoporhs of quartz and feldspar. The groundmass is composed of cataclastically comminuted, extremely fine-grained quartz and alkali feldspar(?) with somewhat less fine grained biotite, chlorite, muscovite, and epidote distributed throughout or in distinct streaks. Some very coarse, schistose bands of muscovite, biotite, epidote, and quartz do occur. Quartz and feldspar blastoporphs are typically somewhat rounded or lens-shaped, and show granulated margins.

The presence of primary or original muscovite and perthitic orthoclase implies a non-volcanic or plutonic provenance for some of the detritals in this formation. However, other materials present are certainly volcanic in origin, and in some cases the volcanic constituent is clearly dominant. Therefore, the original rock is postulated to be a mixture of arkosic sandstone and acid volcanic detritus. Whatever the original nature of the rock, it has undergone severe shear stress under metamorphic conditions equivalent to the Greenschist facies, and one or perhaps two hydrothermal events.

2. Acid Volcanic from the Long Hills

The Long Hills of the Horlick Mountains are located at about 85°20'S, and 119°W longitude. Acid volcanic rocks form Todd Ridge which is one of the major topographic features of this group of nunataks. A collection of samples of these volcanic rocks was made during the 1964/65 field season and seven of these were chosen for an age determination by the Rb-Sr method. Chemical analyses for three specimens (128-2, 128-4 and 128-10) are presented in Table 1.

The volcanic rocks in the Long Hills are not associated with sedimentary rocks but appear to be in contact with porphyritic quartz monzonite. The nature of this contact is not known and appears to be covered by snow and ice. Both the granitic rocks and the felsic volcanics at Todd Ridge are cut by the post-Ordovician erosion surface and must therefore be Ordovician or older in age.

The acid volcanics from the Long Hills are all very similar petrographically except for specimen 128-5, which will be described separately. The rocks are porphyritic and appear massive in hand specimens. The phenocrysts, which make up 15 to 25% of the rocks, are imbedded in a translucent, medium to dark-gray, aphanitic groundmass. The rocks are so extensively altered that the only remaining primary mineral is resorbed quartz, and possibly minor accessory minerals such as zircon, apatite, magnetite, and leucoxene after sphene. Both potash and soda-lime feldspars were originally present in approximately equal proportion, but with minor exceptions, they are entirely altered to very fine-grained sericite, zeolite, carbonate, clay, and epidote. Euhedral chlorite and bowlingite pseudomorphs, which are variable in abundance from specimen to specimen, but which are never very common, indicate the former presence of mica, amphibole, and pyroxene. Xenolithic fragments are almost invariably present in various stages of disaggregation. These range from siltstone and graywacke to fragments of plutonic aspect. The groundmass is usually a very fine-grained, turbid, felsic mosaic, probably alkali feldspar and quartz, containing tiny beads and plates of epidote, chlorite, and opaque minerals. Many petrographic features indicate that the groundmass was originally glass, which was quite possibly vitroclastic.

Some specimens show irregular streaks and patches of relatively coarse quartz and pistacite partially replacing groundmass materials. Deformational features such as crushed grains, microfaulting, and calcite veins are typical.

On the basis of chemical analyses, petrographic features, and observed and interpreted mineral compositions, most specimens can be classed as quartz latites, although compositions may have ranged from dacite to rhyolite. No unequivical evidence was found to indicate the origin of the rocks, but the weight of petrographic evidence favors a pyroclastic origin (ash flow?) rather than lava flow. The rocks have gone through a moderately severe hydrothermal event in which silica may have been added. Slightly earlier than the hydrothermal action or contemporaneous with it, was a period of brittle extensional deformation.

Specimen 128-5 differs from the foregoing in that it is coarser grained and distinctly banded. The rock is composed of abundant phenocrysts of quartz and partially altered orthoclase and albite or sodic oligoclase. The bands are composed mostly of chlorite showing a phyllitic sheen, and are apparently zones of dislocation. In addition to chlorite, the bands contain patches or euhedra of pistacite, clinozoisite, carbonate, carbonate-rimmed fluorite, sphene, apatite, partially hematized magnetite, and quartz. Cutting the rock in many different directions, but generally at high angles to the bands, are numerous veins. These are composed of calcite, epidote, and chlorite. The veins are in part filled extension fractures and in part replacements of the groundmass materials along the fractures, and blend imperceptibly into the banded zone which presumably are the source of the mineral matter.

Unlike the Long Hills volcanic rocks described previously, this material probably originated as a thick lava flow or as a hypabyssal intrusive, which has undergone shearing and extension. Fracture fillings and replacements indicate hydrothermal activity similar to the other volcanic rocks.

3. The Hawkes Porphyry and the Gambacorta formation of the Neptune Range, Pensacola Mountains

The geology of the Neptune Range of the Pensacola Mountains has been described by Schmidt et al. (1965) and Schmidt et al. (1963). The Gambacorta formation rests conformably on the Nelson limestone which unconformably overlies the Patuxent formation. Marine fossils from the Nelson formation date this formation as Middle Cambrian and possibly, in part, Early Cambrian. The Gambacorta formation consists of interlayered dark-brown, red-brown and light green rhyolitic flows, volcanic breccias, pyroclastic deposits and detrital sandstones and conglomerates. Most of the rocks have been intensely altered. The Gambacorta formation is overlain conformably by the Wiens formation which consists of thin-bedded shale, siltstone and fine-grained sandstone. The Wiens formation is unconformably overlain by about 15,000 feet clastic sedimentary rocks of lower to upper Paleozoic age which may be equivalent to the Beacon rocks.

The Hawkes porphyry occurs in the form of sills and in irregular-shaped bodies as much as 5 miles in diameter. It intrudes the Nelson limestone and is chemically very similar to the Gambacorta volcanics which occupy the same stratigraphic position. The field evidence is overwhelming in favor of a Late Cambrian to Early Ordovician age for both the Gambacorta and the Hawkes volcanics.

Five specimens of volcanic rock form the Neptune Range have been analyzed for an age determination by the Rb-Sr method. Two of these (#290 and #291) are rhyolite from the Gambacorta formation, two belong to the hypabyssal phase of the Hawkes porphyry (#292 and #293), while sample #294 is a pyroclastic rhyolite from the base of the Elliott formation which occurs above the unconformity cutting the Wiens formation. Chemical analyses for three of the five specimens are presented in Table 1.

The Hawkes Porphyry is a striking porphyritic rock composed of orthoclase, oligoclase, and quartz phenocrysts in a dusky-red aphanitic groundmass. The feldspar phenocrysts are euhedral except where they are angular because of breakage, and quartz is rounded presumably because of resorption. Not detectable in the hand specimen, but visible in the thin section are remnants of mafic minerals that resemble biotite and hornblende. They are euhedral, and consist of a granular core of quartz, pistacite, and magnetite, with a partially hematized magnetite rim. Also visible in section are lossely compacted glomeroporphs and xenoliths of plutonic aspect. Mineralogically they are similar to the rock in general, but texturally they contrast strongly. Potash feldspar is turbid with clay(?), beads of epidote, minor sericite, and flakes of hematite. Some larger crystals are partially replaced by coarse patches of pistacite, some clinozoisite, abundant chalcedonic quartz, and a dark-green material resembling biotite. Plagioclase is distinctly fresher than orthoclase, although epidote and sericite are invariably present. The groundmass is a fine-grained mosaic of felsic minerals, chiefly quartz and potash feldspar, with a splotchy appearance and spherulitic extinction. Scattered throughout the groundmass are abundant tiny grains of hematite, magnetite, and epidote. Mineralogically the rock is rhyodacite, but chemically it is closer to rhyolite. However, petrographic evidence strongly suggests addition of silica to the system, which would make interpretation of the chemical analysis somewhat ambiguous. The groundmass in the Hawkes Porphyry looks suspiciously like devitrified glass. In places a tenuous flow structure seems to be preserved, but many petrographic features suggest a vitroclastic texture.

Specimen 291 of the Gambacorta formation is an aphanitic, greenish-gray rock with dark greenish-gray streaks and splotches that define a crude banding. No minerals are recognizable in hand specimen, but the thin section discloses euhedral phenocrystic oligoclase (An 22) that is greatly altered to a bowlingite-like mineral and sericite, and is replaced by carbonate. No phenocrysts of quartz or mafic minerals are present, and there is no unequivical evidence for potassium feldspar, because of extensive alternation. Most of the rock is composed of extremely fine-grained felsic material that shows spherulitic extinction and is turbid with an abundance of opaque or nearly opaque beads and grains. Angular fragments up to 5 mm long showing contorted "flow structure", flattened jagged shards less than 1 mm long draped over phenocrysts, and pumice fragments are very abundant. These suggest a welded vitroclastic texture. Along irregular fractures, clast boundaries, and phenocryst margins is abundant granular, nearly opaque material resembling epidote. This material corresponds to the dark, greenish-gray streaks that are visible in the hand specimen. The rock is cut by chalcedony veins containing carbonate, both of which have been strained and partially granulated. The rock is probably latitic in composition and part of a welded ash flow deposit. It is thoroughly devitrified and altered, and has probably gone through a hydrothermal event and a period of weak deformation.

Specimen 290 of the Gambacorta formation is a slightly porphyritic rock with an aphanitic groundmass showing distinct flow structure. It is predominantly light grayish red with dark reddish-brown streaks and medium dary-gray, knot-like inclusions (pumice fragments ?). Phenocrysts, which make up less than 20% of the rock, consist of dark, hematite-stained, strongly embayed, smoky quartz 2 to 3 mm in diameter, and less abundant euhedral pseudomorphs of sericite after feldspar (probably both alkali and alkali-lime feldspar) 1 to 2 mm long. There is a notable lack of mafic minerals except for partially hematized aggregates of magnetite. Microscopically, the groundmass is dominated by streaks and ovoid bodies of sericite, spherulitic alkali feldspar, and axiolitic patches of sutured quartz. Beads of epidote, hematite, and magnetite are ubiquitous. Ovoid inclusions differ from the groundmass in that they show greater abundance of quartz and granular magnetite.

The inclusions are set off from the groundmass by concentrations of hematite along their ragged rims.

There is no strict mineralogical basis for classification of this specimen, but petrographic features suggest porphyritic rhyolite is a reasonable approximation. The rock was probably part of a glassy lava flow containing pumice fragments, although it might have been vitroclastic originally. The unit was not deformed, but it probably went through a hydrothermal event sometime following deuteric alternation.

Specimen 294 of the Elliott formation, for which no section was available, contains quartz and feldspar phenocrysts enclosed in a very pale red, aphanitic groundmass. Quartz phenocrysts are slightly smoky, well-rounded, 1-3 mm in diameter, and comprize 10-15% of the rock. Altered, slightly pinkish milky white, euhedral alkali feldspars, up to 5 mm long are present, but comprise less that 5% of the rock. The presence of altered plagioclase is indicated by euhedral formes composed of a very pale grayish-green material. This mineral makes up 5-15% of the rock. The specimen is probably a rhyolite and is extensively altered.

Age Determinations

Specimens of acid volcanic rock from the three mountain ranges discussed above have been analyzed for age determinations by the total-rock Rb-Sr method. The procedure for these analyses is standard and has been described by Chaudhuri and Faure (1967). The analytical data are compiled in Table 2.

An age was calculated for each of the three suites of samples by

Table 2 - Summary of the Analytical Data for the Acid Volcanic Rocks, Transantarctic Mountains

Sample Number	Rb ppm	Sr ppm	$\frac{Rb^{87}}{Sr^{86}}$	$\left(\frac{Sr^{86}}{Sr^{86}}\right)_{corr}$
		Neptune Range, Pensacola Mountains		
290	262.6	168.4	4.519	0.7311
	261.1	169.0	4.478	0.7319
291	115.2	241.5	1.384	0.7207
	114.2	244.4	1.356	
292	130.0	166.0	2.268	0.7214
293	144.3	136.5	3.064	0.7286
294	140.6	132.2	3.085	0.7292
		Long Hills, Horlick Mountains		
128-2	248.8	22.2	33,08	0.9333
128-3	247.9	46.0	15.83	0.8277
128-4	238.0	59.2	11.73	0.7987
128-5	178.9	42.5	12.28	0.7997
128-6	303.4	44.6	19.96	0.8526
	296.3	46.1	19.10	0.8592
128-9	244.9	52.4	13.66	0.8198
128-10	204.5	69.2	8.602	0.7748
		Leverett Formation, Byrd Mountains		
228	171.9	127.9	3.901	0.7420
231	200.7	103.1	5.655	0.7534
232	129.5	139.7	2.688	0.7337
233	214.6	121.1	5.147	0.7514
				0.7501

Corrected for isotopic fractionation, assuming Sr^{86}/Sr^{88} = 0.1194.

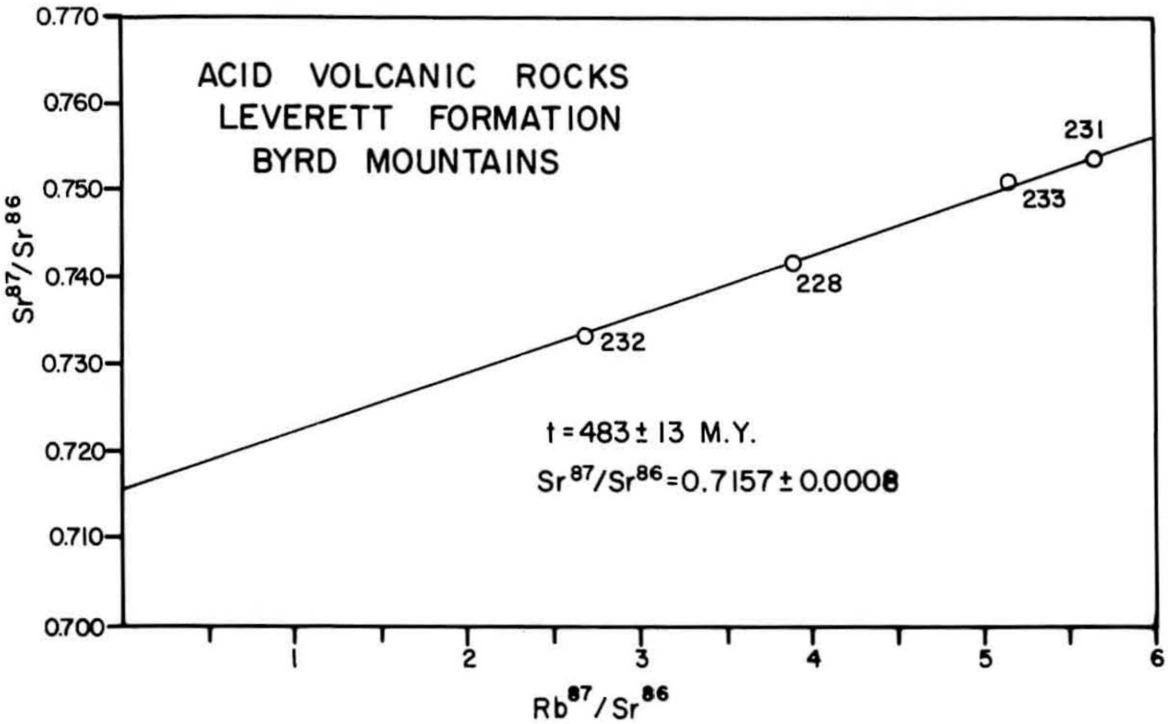

Figure 2 - Acid volcanic rocks from the Leverett Formation of the Byrd Mountains.

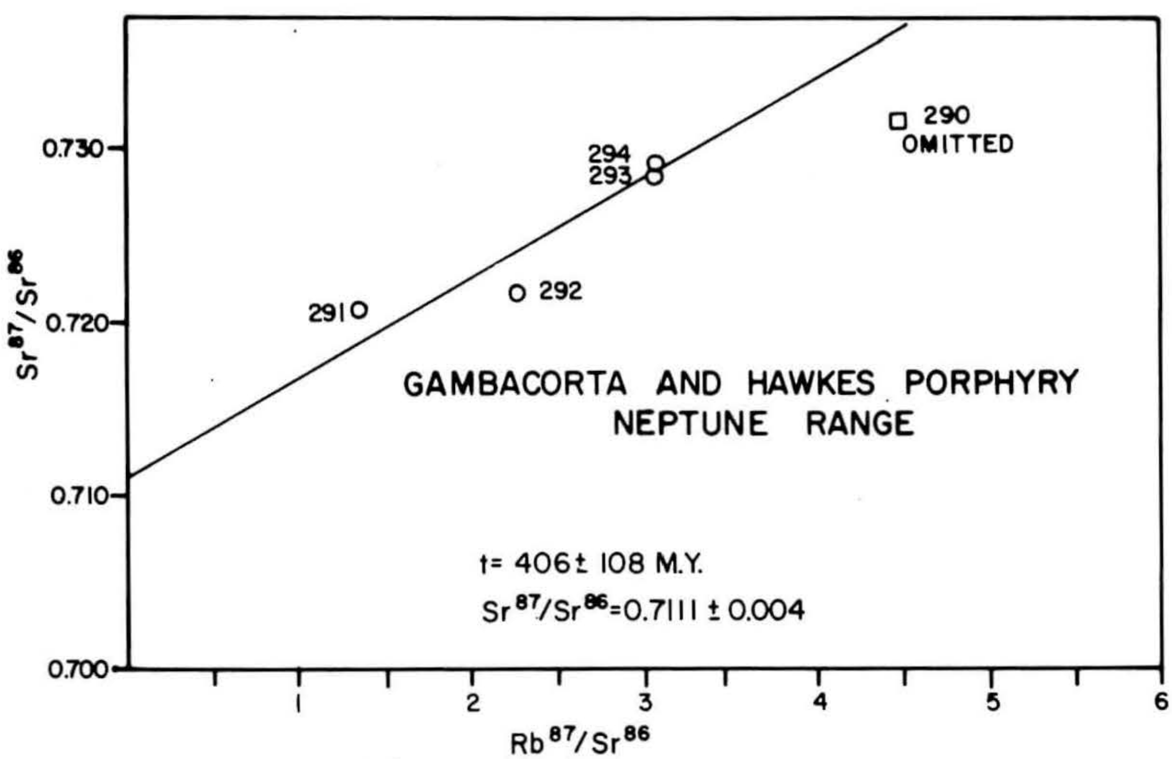

Figure 3 - Rhyolite and rhyolite porphyry of the Gambacorta Formation and the Hawkes porphyry, Neptune Range, Pensacola Mountains.

the isochron method. A straight-line isochron is formed in coordinates of Rb^{87}/Sr^{86} and Rb^{87}/Sr^{86} by a suite of comagmatic rock samples, provided the following conditions are satisfied: 1. All rocks have the same age and the same initial Sr^{87}/Sr^{86} ratio; 2. All rocks have remained closed systems since crystallization. Failure of any one of these assumptions to be satisfied will generally lead to a scattering of data points on the isochron plot. Most of the specimens included in this study have been structurally deformed and may have been chemically altered at the time of crystallization, or at a later date. The results of the age determinations must therefore be interpreted with some caution.

a. Leverett Formation, Byrd Mountains

The four specimens of acid volcanic rock from the Leverett formation are plotted in Figure 2 and form a satisfactory isochron. The age which is calculated from the slope of this isochron is 483 ± 13 m.y., while the initial Sr^{87}/Sr^{86} ratio is 0.7157 ± 0.0008.

b. Gambarcota Formation and Hawkes Porphyry, Neptune Range

Five specimens of rock have been analyzed and are plotted in Figure 4. Two of these (# 290 and 291) are from the Gambacorta formation, two are from the Hawkes porphyry (# 292 and 293), while specimen # 294 is a pyroclastic rhyolite flow from the base of the Elliott sandstone which overlies the Brown Ridge conglomerate which rests unconformably on the Wiens formation. (Schmidt et al., 1965).

These five rocks do not define a unique straight line, which suggest either that they are not comagmatic or that they have been contaminated or chemically altered during their emplacement, or after crystallization. On stratigraphic grounds, the Gambacorta formation must be Late Cambrian to Early Ordovician since it is conformable with the Nelson limestone which contains marine fossils of Middle Cambrian age. The Hawkes porphyry intrudes rocks of the Wiens formation but has supplied boulders to the overlying Brown Ridge conglomerate. It too should be Late Cambrian to Early Ordovician in age.

The two specimens of rhyolite of the Gambacorta formation (290, 291) together indicate an apparent age of about 250 m.y. This value is clearly not the time of crystallization of this rock but reflects the effects of subsequent alteration.

A similar event may be the cause of the discordant ages of the Serpan Gneiss which occurs on the northern end of the Washington Escarpment in the NE Neptune Range. According to a written communication by Dr. D. L. Schmidt the following ages have been obtained for this rock by the Isotope Branch of the U.S. Geological Survey:

Rb-Sr, whole rock,	510 ± 30 m.y.*
K-Ar, biotite ,	265 ± 13 m.y.
Pb alpha, zircon ,	350 ± 40 m.y.

* Half life of $Rb^{87} = 1.47 \times 10^{-11}$ yrs.$^{-1}$

According to Dr. Schmidt, a post-Permian to mid-Mesozoic metamorphic event in the Neptune Range of the Pensacola Mountains is indicated by the folding of Permian Glossopterid-bearing coal measures and the presence of a few small dikes of biotitic lamprophyre. K-Ar age determinations of three biotite concentrates from these lamprophyres give dates of 219, 233 and 244 m.y. (Schmidt, written communication).

The two specimens of Hawkes porphyry (# 292, 293) together give an apparent age of about 670 m.y. This value is also inconsistent with the stratigraphically inferred age of this intrusive. Four additional specimens of Hawkes porphyry are being analyzed in an effort to clarify the data.

The single specimen of rhyolite from the Elliott formation (# 294) cannot be reliably dated because of its low content of radiogenic Sr^{87} and the uncertainty of its initial Sr^{87}/Sr^{86} ratio.

The isochron in Figure 4 was drawn by omitting specimen # 290. The slope of the resulting isochron indicates a value of $t = 406 \pm 108$ m.y. This date surely has little meaning and should be ignored until more data will permit a more meaningful interpretation of the isotope systems.

c. Long Hills, Horlick Mountains

Seven specimens of acid volcanic rocks from Todd Ridge of the Long Hills have been analyzed. The data are plotted in Figure 4 and form a rougly linear array. Specimen 128-2 was omitted from the interpretation because its Na_2O content is only 0.23%, which is approximately one tenth that of the other specimens from this locality (See Table 1 for a comparison of the chemical compositions). Evidently specimen 128-2 has lost sodium and may therefore also have lost radiogenic strontium. In view of this evidence, we cannot ignore the possibility that the other specimens have also been chemically altered. The apparent age of the remaining suite of specimens is 532 ± 38 m.y. and the initial

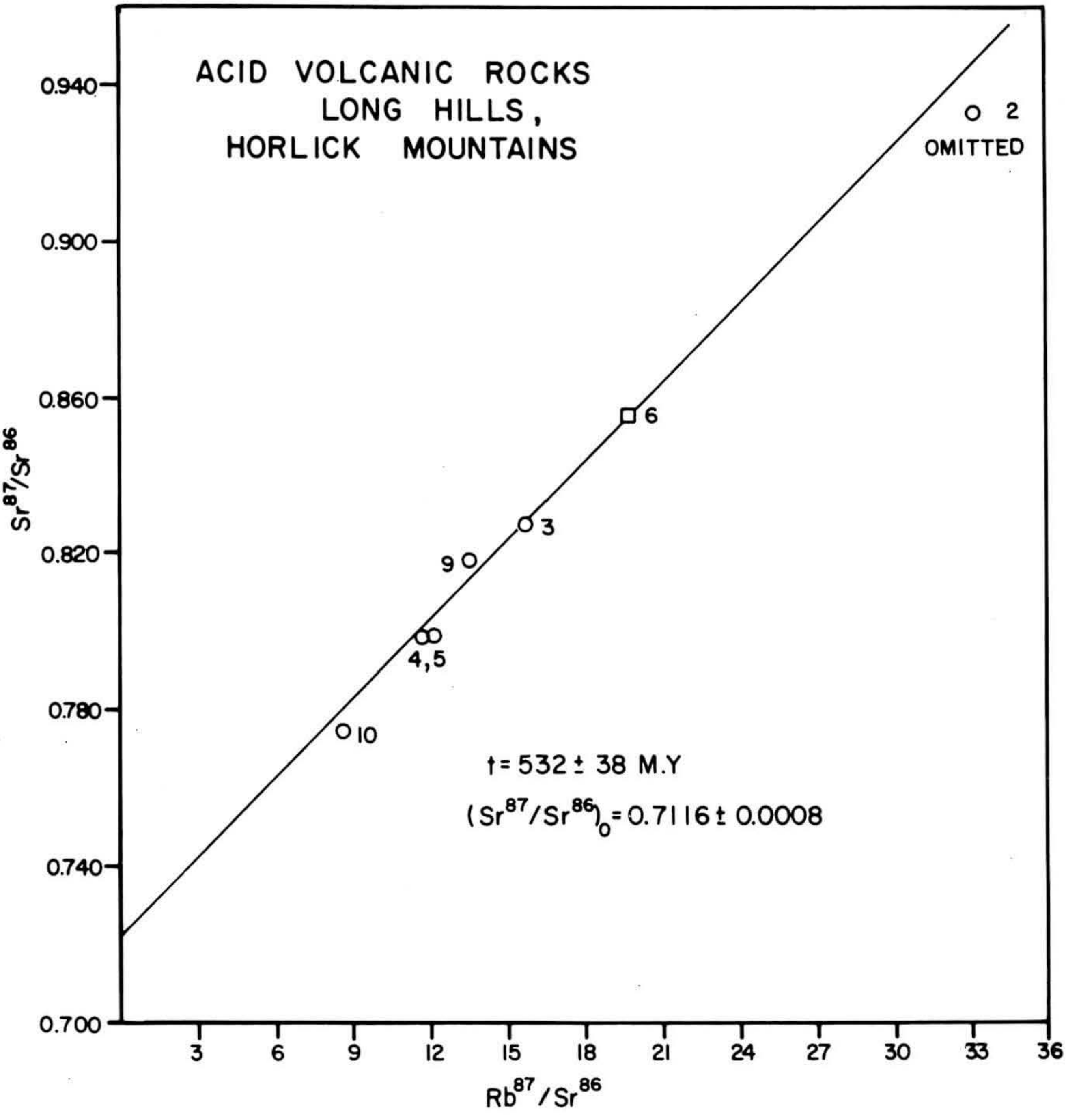

Figure 4 - Acid volcanic rocks from Todd Ridge, Long Hills, Horlick Mountains.

Sr^{87}/Sr^{86} ratio is 0.7116 ± 0.0008. This date indicates a Middle to Upper Cambrian age for these volcanics and suggests that they are to be correlated with the Cambrian volcanism of the Byrd Mountains and the Neptune Range.

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References

Schmidt, D. L., J. H. Dover, A. B. Ford and R. D. Brown, 1963, Geology of the Patuxent Mountains. In R. J. Adie, ed., Antarctic Geology: New York, John Wiley and Sons, pp. 276-283.

Schmidt, D. L., P. L. William, W. H. Nelson, and J. R. Ege, 1965, Upper Precambrian and Paleozoic stratigraphy and structure of the Neptune Range, Antarctica. U.S. Geol. Survey Prof. Paper 525-D, pp. D 112-119.

Minshew, V. H., 1967, Scott Glacier and Wisconsin Range areas, central Transantarctic Mountains, Antarctica. Ph.D. dissertation, Dept. of Geology, Ohio State University.

Chandhuri S. and G. Faure, 1967, Geochronology of the Keweenawan rocks, White Pine, Michigan. Econ. Geol., vol. 62, pp. 1011-1033.